AN INVESTIGATION OF FACTORS RELEVANT TO DEVELOPMENT OF TEAK PLANTATIONS IN SOUTH EAST ASIA WITH PARTICULAR REFERENCE TO BURMA

by

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Except where specific reference is made to the work of another person, the research reported in this thesis is my own original work.

Ko Ko Gyi.

SUMMARY

A detailed review was made of the factors affecting the establishment of teak (Tectona grandis Linn. f.) in plantation to provide a general guideline for such work.

Teak occurs naturally in India, Burma, Thailand and Laos within a rainfall limit of 760 - 5,080mm. The species requires at least two months of definite dry season and cannot tolerate inundation or severe drought. Teak cannot stand stiff clayey nor lateritic soil and prefers a well drained deep alluvium or sandy loam soil. Soil structure is considered more important than nutrient status for teak growth.

The review of teak nursery technique indicated the use of a temporary nursery to be the best where scattered small areas are to be regenerated. It is not very reliable to use a site for a permanent nursery for more than seven years. The use of semi-permanent nursery or rotational use of the nursery site is suggested. A suitable initial spacing is 1.8 x 1.8m. Thinning should be carried out frequently and regularly to get good response and to prevent serious erosion.

Procedures for tree breeding are discussed. Due to the need for late flowering trees and ease of reproduction of the species vegetatively, the use of clonal seed orchards is suggested. Where control-pollination is required, isolation and emasculation should be carried out within one hour of the flowers becoming fully opened. The best time to carry out pollination is between 10 a.m. and 3 p.m. Control-pollination is however very tedious. For the above reasons open pollinated progeny tests are preferable.

Due to the poor and sporadic nature of germination of teak seed, pretreatment experiments were carried out. From these experiments, the alternate soaking and drying pretreatment was found to be most suitable. Germination increased with the increase in period of pretreatment from one week to four weeks. Variation in germination with provenance showed the Southern Burmese provenance to be more superior in germination than the Northern Burmese provenance.

Teak has been recorded as growing well within the shade temperature range of 12.5°C - 40°C. However, studies with teak seedlings under controlled environment demonstrated very poor development at temperatures of 15°/10°C (day/night). Seedlings grew well at 21°/16°C but the best development was observed at 36°/31°C. Growth of teak seedlings increased with the increase of both day and night temperatures within the range studied.

A study of the effect of photoperiod on the development of teak seedlings under controlled environments showed an increase in growth with an increase in photoperiod from eight to twelve hours. No further response was observed with an increase to 16 hours. Photoperiod is probably of little effect on teak growth in the field.

Further studies of provenance variation showed that in growth performance, the Northern Burmese provenance was generally the best and the Indian the poorest. Other provenances showed variation with temperature. The Javanese provenance performed well at higher day and night temperatures while the Souther Burmese provenance prefers the other extreme of the temperature studied. The Laotian provenance showed preference for higher night temperature.

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INTRODUCTION

Teak (Tectona grandis Linn. F.), which occurs naturally in South East Asia, is one of the most important timber species in the tropics. It is an all round utility timber, and the properties possessed by teak, namely, strength, hardness, durability, stability, anti-corrosiveness, anti-fungal, anti-termitic, easily workability, and good appearance, have made it a greatly sought-after timber, (Howard, 1948; Da Costa et al., 1958, 1961; Rudman et al., 1966). Due to these properties, it is extensively used for ship decking, construction of railway carriages, door and window frames, flooring, laboratory tables, panelling, and most of all for furniture making. The demand for teak in the world market is very high, and consequently, many tropical countries outside the natural teak zone are either now introducing teak as an exotic or considering doing so (Lamb, 1957; Chalmers, 1962; Streets, 1962; Cameron, 1963; Horne, 1966).

Despite the importance of teak as a timber species, there exists neither a comprehensive summary of factors relevant to development of teak plantations nor a detailed map of the natural distribution of the species, (Keiding, personal correspondence). Consequently, there is a danger the introduction of the species may be conducted haphazardly. In such a situation, deductions may be made on the results obtained from trial plots without taking into account the teak provenances concerned, the suitability of the locations for teak, or the problems associated with the species in plantation form.

In this thesis, the information available on teak has been summarized to provide a reference from which tentative guidelines could be drawn to assist plantation programmes. The value of the species has been demonstrated by a close examination of the economy of one country in particular (Burma). Possible future developments of teak forestry of Burma are considered, including the need for extensive plantation establishment programmes. General plantation procedures for the species are reviewed, and the difficulties of plantation establishment of teak are discussed. An examination of the species distribution and variation and a review of the forest types with which the species is associated are included as essential aids to plantation establishment.

The major problems associated with teak plantations include:

(i) The difficulty of obtaining adequate seed germination both in the field and in the laboratory.

(ii) A lack of knowledge of the major climatic factors associated with variation patterns within the species.

Both these problems are examined, using experimental procedures. The former in detail and the latter by means of a preliminary study using seedling material in controlled environments.

The review and the experiments have enabled some definite guidelines to be determined for the establishment of teak in plantation either as an indigenous species or as an exotic for South East Asia. Less definite suggestions are made for establishment elsewhere.

CHAPTER 1

THE IMPORTANCE OF THE BURMESE TEAK FOREST RESOURCE

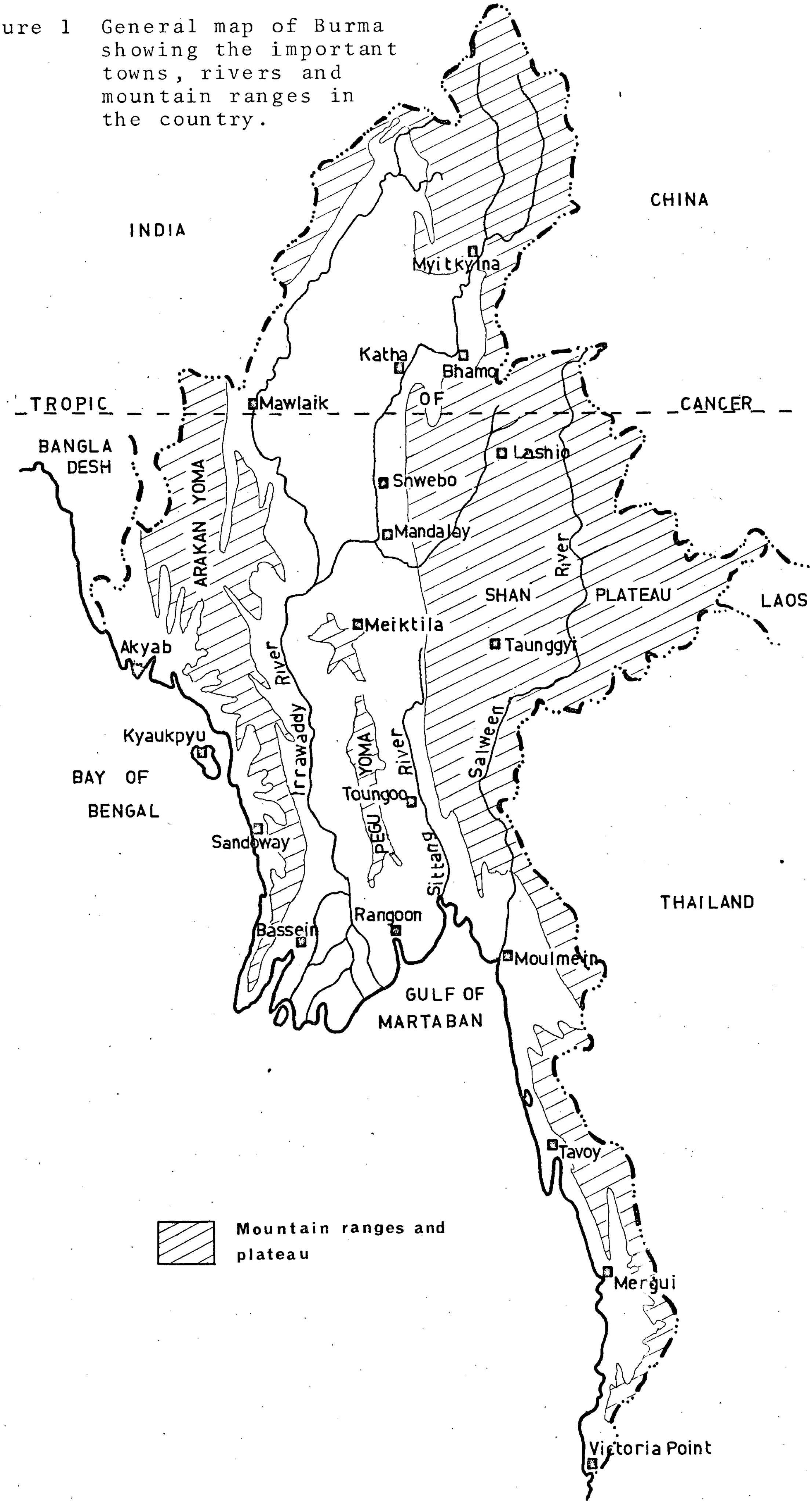
1.1 General

Burma has a total area of 677,782 sq km and is situated within latitudes 29°N and 10°N with approximately 75 per cent of the country within the tropics. The country has over 1,900 km of continuous coastline to the southwest along the Bay of Bengal. Inland, Burma has common boundaries with the Republic of Bangladesh, India, China, Laos and Thailand (Figure 1).

Topographically, the country has three major drainage systems based on the rivers, Irrawaddy, Sittang and Salween, all three of which run from north to south, separated by mountain ranges and plateaux (Figure 1). These rivers, with their major tributaries provide over 8,000 km of commercially navigable waterways, and an additional several thousand kilometres can be used by small local crafts (boats and sampans) (Anon 1952). The rivers are widely used and provide the major transportation system. Consequently, the major towns and cities are usually situated on waterways.

Burma has a population of 28 million and the two principal cities of the country are Rangoon and Mandalay (Figure 1). Rangoon, the capital and business centre is also the largest port and has a population of approximately 1.8 million. Mandalay, the second largest city of the country

Figure 1 General map of Burma showing the important towns, rivers and mountain ranges in the country.



was the last capital of the Burmese kings. It is the only major inland city, but is closely linked to Rangoon by waterway and also by rail, road and air.

Other cities and towns of commercial importance however are mainly seaports. Apart from Rangoon, there are five major seaports which include Akyab, Bassein, Moulmein, Tavoy, Mergui and other ports of lesser importance include Kyaukpyu, Sandoway and Victoria Point (Figure 1).

The country is largely underdeveloped with the people heavily dependent on natural resources, and particularly on agriculture. This dependence is evident in the breakdown of the gross national product (GNP) (Table 1). 32.6 per cent of the GNP is attributed directly to the rural industries of agriculture, forestry and fishery. In addition, a substantial proportion of the contribution from heavy and secondary industry (15.0 per cent), and trade (24.2 per cent) is also based on agriculture and forestry.

The importance of agriculture is further emphasised in the breakdown of the labour force between the various industries (Table 2). 66 per cent of the working population of the country is involved in agricultural work whilst comparable figures for industry and mining are 7.23 per cent and 0.28 per cent respectively. Surprisingly, despite the high proportion of the populace engaged in agricultural work, only 27 per cent of the country is utilized for agricultural production, with only 11 per cent actually under production at any one time, the remaining 16 per cent standing fallow (Anon. 1970a). Clearly, therefore, a very large proportion of the land area is only contributing marginally to the economy of the country.

Table 1. Income from various economic sectors and gross national product of Burma over the period 1959-1964.

(Kyats Million)

Sectors	1959-60	1960-61	1961-62	1962-63	1963-64	
1. Agriculture	1,567	1,627	1,767	1,881	1,789	(23.1%)
2. Forestry	330	361	371	397	356	(4.6%)
3. Livestock and Fishery	352	355	341	364	381	(4.9%)
4. Mining	68	60	67	69	73	(0.9%)
5. Industry (Heavy-secondary)	936	1,022	1,134	1,300	1,157	(15.0%)
6. Power	23	34	27	29	28	(0.4%)
7. Construction	233	217	231	236	230	(3.0%)
8. Transportation	285	280	286	283	286	(3.7%)
9. Trade	1,913	1,875	2,014	2,045	1,870	(24.2%)
10. Banking and Insurance	90	95	106	99	94	(1.2%)
11. General Government	637	654	686	733	780	(10.1%)
12. Service and Rental Value	643	652	676	681	671	(8.7%)
13. Gross Domestic Product	7,077	7,232	7,706	8,117	7,715	
14. Nett Income payment to abroad	13	19	4	2	- 16	
15. Gross National Product	7,064	7,213	7,702	8,115	7,731	

Source - The National Income of Burma, 1964.

(Kyat 1 = $(A)0.15)

Table 2. Working population by occupational group in Burma.

Occupational group	No. of working population	% of working population
1. Agriculture	7,078,320	66.00
2. Forestry	102,094	0.95
3. Fishery	167,513	1.56
4. Mining, Quarrying and Drilling	29,965	0.28
5. Industry	775,312	7.23
6. Electricity	13,383	0.12
7. Construction	98,938	0.92
8. Transportation and Communication	339,635	3.17
9. Social Welfare	134,300	1.25
10. Managerial, Administrative Clerical and Related	324,650	3.03
11. Trade and Commerce	955,508	8.91
12. Ad hoc	705,400	6.58
Total Working Population	10,725,017	100.00
Total Burma Population	27,600,000	-

Source - Report to the People, 1970-71.

The quoted figure in Table 2 for the proportion (0.95 per cent) of the work force engaged in forestry is misleading. All the major agricultural crops produced including paddy, pulses, maize, sesamum, groundnut, potatoes, cotton, tobacco, sugar cane and jute are seasonal in their labour requirements. Thus, many of the population listed in Table 2 as engaged in agricultural work would not be so engaged throughout the whole year. In the off season, many would be engaged in other occupations, particularly forestry. Forestry therefore whilst contributing directly to the GNP of the country also provides stability for the labour force and relieves the unemployment problem of agricultural labour during the off season.

1.2 The importance of the timber resources to the Burmese economy

The main export commodities of Burma are rice, other agricultural products, mining products including silver, base metals and ores, and also paraffin wax, and timber, particularly teak (Table 3). The trading section is heavily dependent on the agricultural, forest and mining products, for these are the only products presently able to compete in foreign markets and capable of earning substantial quantities of foreign exchange.

Rice constitutes the main export of the country and has done so for many years (Table 3). From 1955 to 1957, Burma's rice export accounted for approximately 30 per cent of the world's total, with the country as the world's largest rice exporter. However, since early 1962, export of rice has steadily declined (Figure 2). By 1969, the situation had deteriorated to the stage where Burma had lost its role as

Table 3. Details of the principal commodities exported from Burma over the period 1959-69

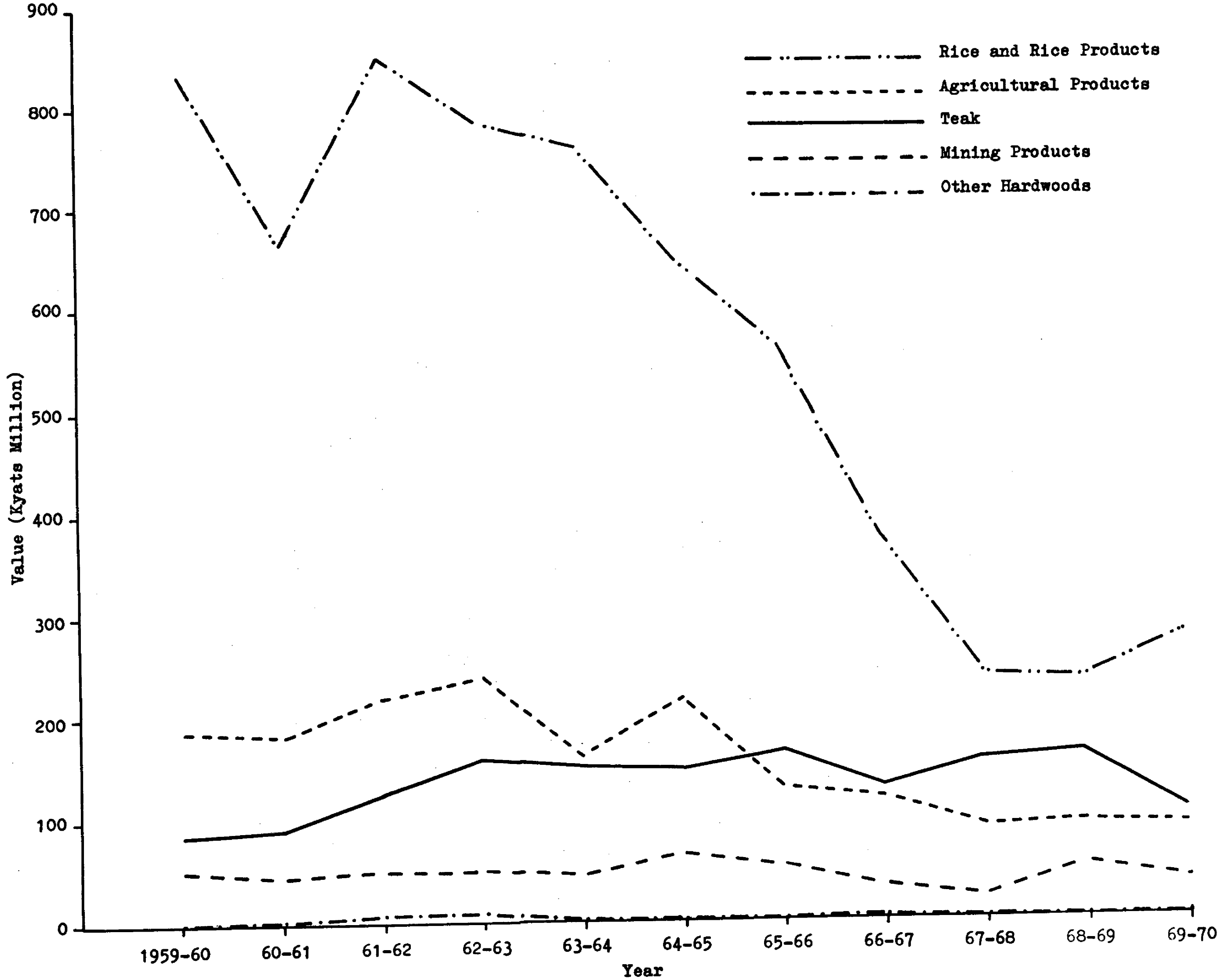
(Kyats Million)

Period	Rice and rice products	Other agricultural products	Mining products	Teak	Other hardwoods
1959-60	834.8	186.3	50.9	86.1	2.7
1960-61	664.4	180.9	45.8	91.3	2.9
1961-62	852.1	217.8	48.3	125.0	7.1
1962-63	784.1	239.3	49.4	157.4	7.7
1963-64	760.8	159.5	55.8	149.4	1.8
1964-65	644.9	214.0	62.9	146.8	1.2
1965-66	562.8	127.4	53.2	163.0	0.3
1966-67	375.0	115.1	31.8	128.0	2.6
1967-68	238.1	88.4	21.6	154.7	0.3
1968-69	235.3	90.3	51.0	159.6	0.4

Source - Selected Monthly Economic Indicators, March 1971.

(Kyat 1= $(A)0.15)

Figure 2 Graph showing the export value of principal commodities in Burma and the decline in rice export



the world's leading rice exporting country to the United States of America, and Burmese rice accounted for only seven per cent of the world's total export. The drop in rice export is made more serious by the 'Green Revolution' under which many people, particularly Japanese are changing from rice to wheat as the staple diet. Prospects for a substantial improvement in future rice exports from Burma are therefore not good. Exports of other agricultural products have also declined from Kyats 214 million to Kyats 90 million over the period 1964-69. In 1968-69, Burma clearly depended very heavily on its timber export which constituted 30 per cent of total exports by value although rice was still the leading export commodity. Indeed, in the absence of any indication of mining development, and with the steady decline in rice export, Burma may need to depend even more heavily on timber export in the future.

1.3 Timber production and export

In Burma, forestry administration is divided into two sections, namely the Forest Department and the State Timber Board. The Forest Department is responsible for all the silvicultural works in the forests, i.e. regeneration, improvement and marking of trees for extraction. The State Timber Board is responsible for extraction, milling and marketing of trees selected by the Forest Department.

At present, the forests of Burma are capable of maintaining a sustained annual yield of 450,000 tons of teak and 2,400,000 tons of other commercial hardwoods (Maung Gale (1),

Table 4. Timber production in Burma over the period 1959-69.

Year	Girdling of teak		Extraction (tons)	
	No. of trees	Tons (estimates)	Teak	Other hardwoods
1959-60	181,436	272,154	249,834	574,751
1960-61	181,436	272,154	292,724	671,480
1961-62	251,964	377,946	282,886	693,787
1962-63	278,635	417,953	313,829	779,471
1963-64	241,328	361,992	381,460	672,487
1964-65	207,710	311,565	261,497	721,033
1965-66	173,103	259,655	239,972	634,510
1966-67	211,999	317,999	287,410	660,942
1967-68	87,780	131,670	*299,129	632,722
1968-69	105,943	158,915	*173,126	536,184

Source - Statistical Year Book 1961, 1963, 1965, 1967.

*Forest Economist, Burma.

<u>Note</u>: Tonnage of girdled trees was estimated by multiplying the number of trees by 1.5 tons.

1968)[1]. However, because of difficulties of extraction and communications, only 280,000 tons of teak and 660,000 tons of other commercially important hardwoods are being extracted annually on average (Table 4).

The export of timber, particularly teak appears to hold very good prospects for Burma. The popularity of teak is due to the combination of an attractive appearance and desirable wood properties, particularly strength, durability, stability, lightness in weight and resistance to corrosion by acids in laboratories (Anon. 1956b, Myint Aung, 1967). It is also easily worked and will probably always be considered a high quality and useful timber. The export price of teak has been rising steadily from Kyats 825 ($A126) per ton to Kyats 1,406 ($A214) per ton within the period 1958 to 1968 (Table 5, Figure 3), indicating high world demand for the timber. Indeed the present world requirement is so heavy that Burma is unable to satisfy the demand (personal correspondence S.T.B.).

One possible threat to Burma's teak markets could be an increase in competition from other teak growing countries. However, Burmese teak is well known and has the established markets throughout the world (Banijbhatana, 1957; Kermode, 1964; Myint Aung, 1967). Also there is a premium placed on quality teak. Quality is determined by both size, strength and appearance. Teak timber is graded firstly according to standard grading rules, covering knot frequency, size and

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[1]When two or more persons, working in the same department have exactly the same name, a situation of common occurrence in Burma, they are referred as (1), (2), and so on, with the most senior person starting with (1). Hence Maung Gale (1) quoted in this thesis is the most senior of the Maung Gales in the Forest Department.

Table 5. Exports of teak (log and sawn timber) from Burma over the period 1948-68

Year	Quantity (tons)	F.O.B. Value (Kyats)	Average price per ton (Kyats)
1948-49	66,817	40,882,330	612
1949-50	15,954	12,024,079	754
1950-51	50,086	45,770,855	914
1951-52	44,564	41,647,119	935
1952-53	28,427	26,492,405	932
1953-54	29,047	25,244,481	869
1954-55	31,533	27,726,217	879
1955-56	56,883	49,036,652	862
1956-57	66,132	60,243,517	911
1957-58	66,430	56,029,591	843
1958-59	73,646	62,412,610	825
1959-60	90,591	86,135,850	951
1960-61	92,035	91,329,383	992
1961-62	119,019	125,018,209	1,050
1962-63	145,889	157,443,437	1,079
1963-64	153,859	149,932,224	971
1964-65	140,068	146,788,113	1,048
1965-66	135,455	162,965,487	1,203
1966-67	100,171	127,966,000	1,277
1967-68	109,991	154,677,000	1,406

(Kyat 1 = \$(A)0.15).

Source - Myint Aung, (1967). 'Marketing of Burma Teak'.

other timber defects, and secondly on the presence or absence of a figure known as 'black stripe'. Table 6 shows the prices fixed by the State Timber Board in 1971 for black stripe and non stripe teak round logs both dry and green, and also thinly striped green teak. Clearly green teak fetches a better price than dry (girdled) teak and black stripe teak a higher price than non stripe teak. Sale is effected by sealed tender, and the prices paid are generally higher than these fixed prices, which may be regarded as the minimum price. An offer of $A4,800 per ton was frequently received by the State Timber Board (personal correspondence, S.T.B.).

Burmese teak has always been considered superior to other naturally occurring teak because of its quality, strength and availability in long lengths and large sizes (Limaye, 1956; Wood, personal communication). Thus, provided the quality and quantity of the timber can be further improved, with competent marketing, Burma should be capable of maintaining its share of the world market. This will necessitate however, considerable attention being paid to quality control of the timber produced.

A number of tropical countries are now establishing teak plantations (Lamb, 1957; Streets, 1962). These include countries in which teak occurs naturally, such as India, Thailand, Laos and Indonesia and others, including, Trinidad, Nigeria and Papua New Guinea, which have introduced teak as an exotic outside the natural teak zone. These teak plantations could be an additional source of competition in the world teak markets in future. Moreover, some countries including Thailand, Trinidad and Papua New Guinea are now engaged in intensive improvement of teak by seed selection and

Table 6. Export prices per ton (50 Hoppus cubic feet) for dry and green teak round logs from Burma (1971)

Quality	Length	Girth	F.O.B. Rangoon in Pound Sterling				
			DRY		GREEN		
			B/S	N/S	B/S	N/S	Thinly striped
First Quality	8' & up	7' & up	238	183	310	219	264
	"	6'0"-6'11"	231	177	300	212	256
	"	5'0"-5'11"	224	171	291	205	248
	"	4'2"-4'11"	197	150	256	179	217
Second Quality	8' & up	7' & up	170	129	221	141	181
	"	6'0"-6'11"	164	122	213	134	174
	"	5'0"-5'11"	157	118	204	130	167
	"	4'2"-4'11"	115	90	150	99	124
	6' - 7'	5' & up	115	90	150	99	124
	"	4'2"-4'11"	100	73	130	80	105
2 star & 2 star Special	8' -16'	6'7"-7'11"	111	96	127	98	-
	"	5'0"-6'6"	101	86	115	87	-
	"	4'0"-4'11"	88	74	103	79	-
	4' - 7'	5' & up	62	53	73	56	-
	"	4'0"-4'11"	55	47	64	49	-

B/S = Black Stripe N/S = Non Stripe (£1 = \$(A)2.04)

Source - State Timber Board, Burma (personal correspondence).

tree breeding (Chalmers 1962; Cameron 1966; Hedegart 1971), and it is probable these countries will also be producing high quality teak in future. Thus, with intensive management, more effective planting and extraction facilities, and presumably intensive marketing, these countries could pose a serious threat to Burma's teak markets.

The future teak forests of Burma are therefore of vital importance to the country. Difficulties of meeting the present demand, the need to meet future competition, and the importance of quality control suggest large areas of high quality teak forests are now needed. Teak plantations are therefore likely to play an increasingly significant role in Burmese forestry. However, plantation teak, to satisfy market requirements and probably even to ensure eventual success of the plantations will need to have a high rate of production and to be composed of high quality material. Careful selection of the plantation material will therefore be necessary so as to ensure maximum production and quality.

CHAPTER II

FOREST TYPES OF BURMA AND THEIR SUITABILITY FOR TEAK PLANTATIONS

There are six major forest types in Burma most of which are further sub-divided. The major types and sub-divisions used by the forest department in Burma in the local handbook 'Departmental Instructions for Forest Officers in Burma' are:-

1. Evergreen Forests
   (a) Tropical wet evergreen
   (b) Tropical semi-evergreen
2. Mixed Deciduous Forests
   (a) Moist upper mixed deciduous
   (b) Dry upper mixed deciduous
   (c) Lower mixed deciduous
3. Deciduous Dipterocarp or Indaing Forests
4. Dry Forests
5. Hill and Temperate Evergreen Forests
   (a) Sub-tropical wet hill forests
   (b) Sub-tropical hill savannah
   (c) Alpine
6. Tidal, Beach and Dunes, and Swamp Forests.

The proportion and distribution of each of the major types in the total forested area are given in Table 7 and Figure 4. Each subdivision is briefly described below with particular attention to the presence and development of

Table 7. Forest types of Burma

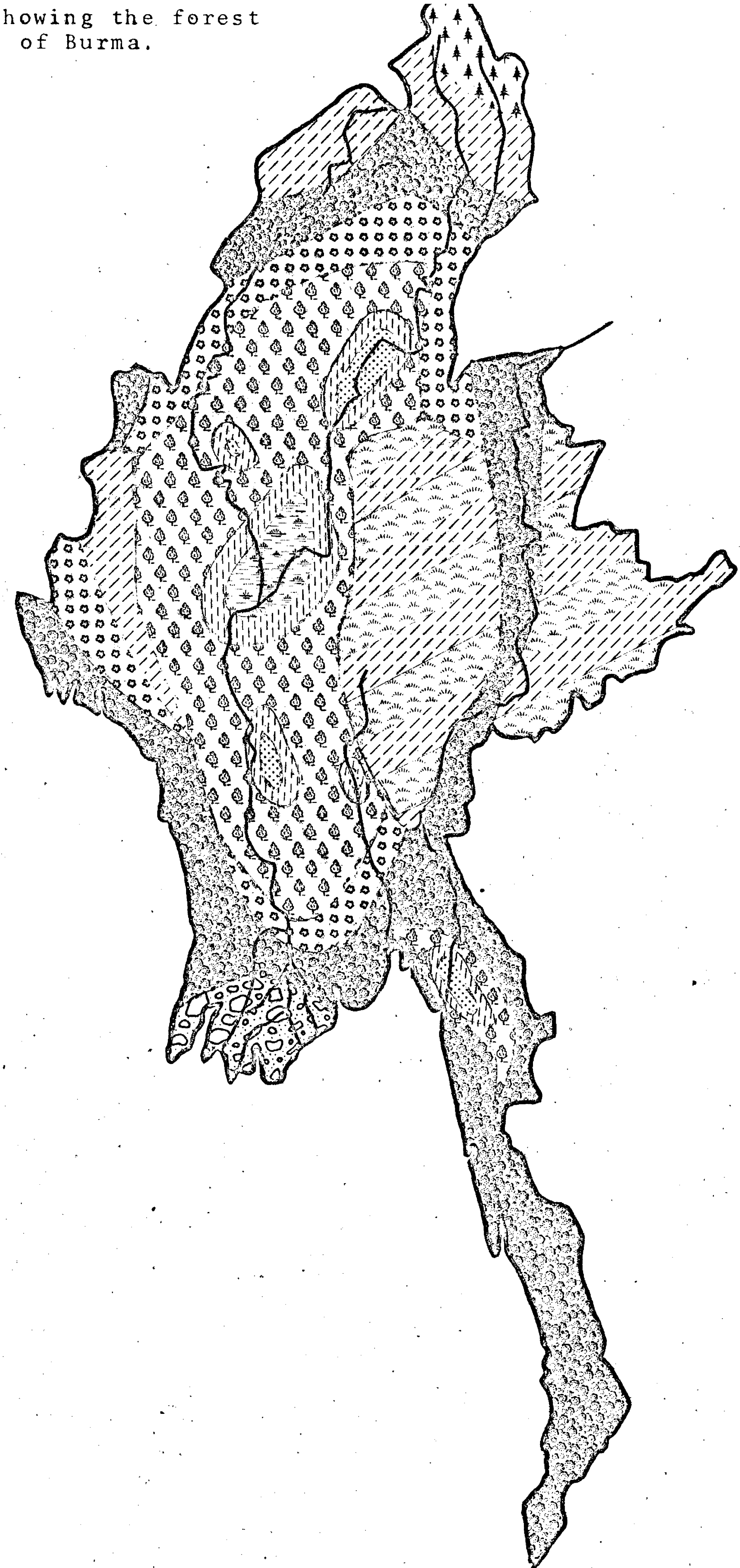
Forest types	% of total forest area
1. Evergreen forests	16
(a) Tropical wet evergreen	
(b) Tropical semi-evergreen	
2. Mixed deciduous forests	39
(a) Moist upper mixed deciduous	
(b) Dry upper mixed deciduous	
(c) Lower mixed deciduous	
3. Deciduous dipterocarp or Indaing forests	5
4. Dry forests	10
5. Hill and temperate evergreen forests	26
(a) Sub-tropical wet hill forests	
(b) Sub-tropical hill savannah	
(c) Alpine	
6. Tidal, beach and dunes, and swamp forests	4

Source - Working Plan Circle, Forest Department, Burma.

References for Figure 4.

(i)	Evergreen Forests	Tropical Wet Evergreen
		" Semi "
(ii)	Mixed Deciduous Forests	Moist Upper Mixed
		Lower Mixed Dry Upper Mixed
(iii)	Deciduous Dipterocarp or Indaing Forests	
(iv)	Dry Forests	Than-dahat Forests Thorn Forests
(v)	Hill & temperate Evergreen Forests	Sub-tropical Wet Hill
		Sub-tropical Hill Savannah
		Alpine
(vi)	Tidal, Beach and Dune and Swamp Forests	

Figure 4 Map showing the forest types of Burma.



teak and also to the general suitability for teak plantations. Full details of the species composition for each type are given in Appendix I.

2.1 Evergreen forests

This type of forest is considered the ecological climax of the Burmese forests (Aung Din, 1951). It constitutes 16 per cent of the total forest land of Burma (Table 7), and is subdivided into (a) tropical wet evergreen and (b) tropical semi-evergreen types.

2.1.1 Tropical wet evergreen

The tropical wet evergreen type occurs in areas with rainfall over 2032 mm or in sheltered moist valleys. Species characteristic of this type include the important commercial hardwoods kanyin (*Dipterocarpus* spp.), yinma (*Chukrasia tabularis* A. Juss.), thitka (*Pentace burmanica* Kurz.), and sagawa (*Michelia champaca* Linn.). Dense masses of evergreen climbers and canes are present as undergrowth, and the bamboo species detailed in Appendix I are characteristic of the type.

2.1.2 Tropical semi-evergreen

The tropical semi-evergreen forest type generally occurs further inland than the tropical wet evergreen. Usually this type is confined to moist and fertile areas and occurs in mosaic pattern with the moist deciduous forest type (described below under section 2.2). The drainage pattern is the prime determinant of the mosaic arrangements.

In the tropical semi-evergreen forests, both evergreen and deciduous dominants usually occur in close association, but the lower storey is predominantly of evergreen species. Typical commercial species in this type of forest include pyinkado (*Xylia dolabriformis* Benth.), yemane (*Gmelina arborea* Roxb.), didu (*Salmalia insignis* Schott and Endl.), letpan (*Salmalia malabarica* Schott and Endl.), and kanyin (*Dipterocarpus* spp.[1]). The bamboos (see Appendix I for species detail) are again characteristic of the forest type. Teak is present but only as scattered individual trees or in small groups in this type of forest. Generally, the teak trees are large and fluted, and little or no teak regeneration is present.

Both the tropical wet evergreen and the tropical semi-evergreen types of forest contain a number of commercially important hardwood species. Consequently, although they contain little or no teak, these forest types are important from the timber production point of view. The tropical semi-evergreen type could be used for teak plantations, but the tropical wet evergreen type could not, it being too wet.

2.2 Mixed deciduous forests

This is the most important forest type in Burma, with teak and many other commercially important hardwoods present. It constitutes 39 per cent of the total forest area (Table 7).

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[1]The term 'kanyin' is applied to several *Dipterocarpus* species in Burma.

The type is sub-divided into (a) moist upper mixed deciduous forest (M.U.M.D.), (b) dry upper mixed deciduous forest (D.U.M.D.) and, (c) lower mixed deciduous forest (L.M.D.).

2.2.1 Moist upper mixed deciduous forest

The M.U.M.D. type occurs in mosaic with the semi-evergreen type as noted above, and is also found over large areas as a pure forest type or in mosaic with the D.U.M.D., the L.M.D. and the deciduous dipterocarp forest (see section 2.3) types. Drainage and soil types are the prime determinants of the mosaic. The M.U.M.D. type occurs on fertile well drained slopes. It carries a good growth of teak usually in association with the important hardwood pyinkado (*Xylia dolabriformis* Benth.). Pyinkado is known as the iron wood of Burma and is ranked second to teak in commercial importance. Other important associate species include padauk (*Pterocarpus macrocarpus* Kurz.), binga (*Mitragyna rotundifolia* O. Ktze.) and yemane (*Gmelina arborea* Roxb.). This forest type is also characterised by the composition and development of the bamboos, full details of which are given in Appendix I.

2.2.2 Dry upper mixed deciduous forest

The D.U.M.D. type normally replaces M.U.M.D. on top of ridges and on slopes with a hot aspect. The type is characterised by much poorer development of the vegetation than the M.U.M.D. forests. This is particularly evident in the bamboo species particularly kyathaungwa (*Bambusa polymorpha* Munro), and tinwa (*Cephalostachyum pergracile* Munro), which become poorly developed in this type. Teak occurs in association with the same species as it does in the M.U.M.D. forests, with the addition of some species characteristic of drier areas, namely thitya (Shorea oblongifolia Thw.), ingyin (Pentacme siamensis) (Miq.) Kurz.), in (Dipterocarpus tuberculatus Roxb.), and panga (Terminalia chebula Retz.).

2.2.3 Lower mixed deciduous forest

The L.M.D. type occurs on lower ground, normally on flat alluvial or clayey sites near streams. It is characterised by the scarcity or absence of bamboo. Teak often occurs in pure stands and may attain large sizes in this type of forest. However, it is often fluted, and is not as cylindrical as in M.U.M.D. or D.U.M.D. types. Other commercial species found together with teak include pyinkado (Xylia dolabriformis Benth.), yon (Anogeissus acuminata Wall.), sit (Albizzia procera Benth.), taukkyan (Terminalia tomentosa W. and A.), (see Appendix I for detail).

Although all these mixed deciduous types can be utilized for teak plantations, the M.U.N.D. type would be selected in preference to the others. Teak plantations, established in D.U.M.D. type of forest can be very slow growing. Moreover, in the Pyinmana forest division of Burma, the author has noticed the development of stag headedness in a portion of 30 year old teak plantation established in the D.U.M.D. type. An area of the same plantation in the M.U.M.D. however was not affected. The L.M.D. type is considered to be too moist for teak plantation, and is liable to produce fluted and inferior timber.

2.3 Deciduous dipterocarp or indaing forests

This type of forest constitutes five per cent of the total forested land of Burma (Table 7), and usually occurs on sandy, gravelly, or lateritic soils up to an altitude of approximately 700 m. It is characterised by the prevalence of in (*Dipterocarpus tuberculatus* Roxb.) which may form over 80 per cent of the species composition. Teak may also be found in this type of forest, but is normally stunted and of very poor quality. Abundant germination of teak seedlings frequently occurs, but these are usually short lived. Studies by Kermode (1964) revealed germination of teak in deciduous dipterocarp forest to be three times better than in mixed deciduous forests.

This forest type is too dry and the soil type unsuitable for satisfactory development of teak, and thus, is undesirable for teak plantation.

2.4 Dry forests

This type of forest occurs in the Central Dry Zone of Burma where the rainfall is less than 1270mm. It constitutes 10 per cent of the total forest land of Burma (Table 7), and consists mainly of stunted trees and thorny bushes including species such as than (*Terminalia oliveri* Brandis), dahat (*Tectona hamiltoniana* Wall.), and sha (*Acacia catechu* Willd.). (See Appendix I for detail). No commercial timber is produced in this type and the area would be unsuitable for teak plantation.

2.5 Hill and temperate evergreen forests

This type of forest constitutes 26 per cent of the total forested land of Burma and is found at elevations exceeding 914 m. Pines, including *Pinus kesiya* Royle ex Gordon and *Pinus merkusii* Jungh. are the important species in this type of forest. However, the pines are used mainly for tapping resin for turpentine and rosin production rather than for timber. This type is also unsuitable for teak plantation.

2.6 Tidal, beach and dunes, and swamp forests

These types of forests constitute only four per cent of the total forested land in the country (Table 7). The tidal forest occurs within the tidal limits in the Irawaddy delta in lower Burma, and consists mainly of mangroves including kanazo (*Heritiera fomes* Buch.) and kyana (*Xylocarpus moluccensis* Lam.), used solely for firewood. The Beach and Dunes type occurs on sandy beaches and dunes and is characterised by the occurrence of kabwe (*Casuarina equisetifolia* Forst.), whilst swamp forests occur in fresh water swamps, usually near rivers and lakes. Trees in this type of forest are normally scattered and small in growth. These areas are also unsuitable for teak plantation.

Forest types where teak plantation can be established are listed below in order of preference.

(i) Moist upper mixed deciduous forest

(ii) Lower mixed deciduous forest

(iii) Tropical semi-evergreen forest

(iv) Dry upper mixed deciduous forest

These make up more than 39 per cent of the total forest area of Burma. All these types are located inland, mainly along the Irrawaddy and Sittang drainage systems with a few areas on the Salween drainage (Fig. 4). Thus teak plantations established in these areas are likely to rely heavily on river transport for utilization of the timber produced. There is however a network of main roads and railways in these areas. Thus, the timber could be extracted as green teak using either the land systems or a water-based barge system. The problem of extracting green teak lies in the movement of the timber from the stump to a central location.

CHAPTER III

MANAGEMENT PROBLEMS IN NATURAL FORESTS AND THE POSSIBILITIES FOR TEAK PLANTATIONS IN BURMA

Burma, like many tropical countries is faced with the problem of the management of extensive mixed natural forests. When scientific management of the forests was introduced over a hundred years ago, a management system known as the Burma selection system was adopted. However, with the increasing demand for teak, and with the failure of the present system to satisfy the demand, there is a need for revision and modification of the management approach.

3.1 Burma selection system

The 'Burma selection system' is a method of exploiting one tree species (teak) from a complex multi-species forest (Kermode, 1964). It has little concern for regeneration of the species, and Aung Din (1956), Haig, *et al*. (1958), and Kermode have all stressed the lack of resemblance of this system to the true silvicultural selection system as described by Troup (1966).

In the Burma selection system outlined by Aung Din (1956) Haig *et al*. (1958), and Kermode (1964), the forest area is divided into 30 blocks of equal yield capacity. Each year, selection fellings are carried out in one of these blocks, and the whole forest is therefore worked over in a period of 30 years. This period is known as the 'felling cycle'. Under the system when felling becomes due, all marketable trees which have attained a fixed exploitable girth size are selected for cutting. The girth size varies with the type of

Moreover, mechanization of the extraction operation is impracticable due to the scattered distribution of the trees, and extraction is dependent solely upon elephant power.

Ecologically, teak bearing deciduous forests in Burma are in a successional stage proceeding towards the evergreen forest type in which teak is not present (Aung Din, 1951; Haig, et al. 1958; Kermode, 1964). Aung Din (1951) strongly believed that the present silvicultural system is accelerating this transformation. He stated 'the defect of the present Burma selection system lies in the presupposition that teak trees come up in place of those girdled and extracted, whereas, even theoretically speaking, teak has only a 12 per cent chance against 88 per cent of other hardwood species of establishing itself in the gap so caused'.[1] Support for this followed from analyses of enumeration studies in Burma by Aung Din (1956). Unspecified areas worked under the Burma selection system showed a reduction in the proportion of teak in relation to the other species. More convincing proof of this process would be desirable, but it has nevertheless been accepted as a fact by many Burmese foresters.

Utilizable teak trees in natural forests are scattered, giving an average of one tree per 3.2 hectares (Office of the Director of Forests, Burma, personal correspondence). Also, the major teak forests in Burma are frequently located in steep terrain. These areas are so inaccessible that only teak, which is floatable, can be worked economically. These two factors present severe problems of extraction.

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[1]Teak was estimated to constitute approximately 12 per cent of the population in the mixed deciduous forests in Burma at that time.

Mechanization is frequently impracticable, and elephants had to be used for pushing or dragging teak logs to the stream for floating. Logs are then floated to rafting stations where they are constructed into rafts for further transportation along the river to the main cities.

A severe reduction in the number of elephants during the second world war has greatly hindered extraction and production of teak. The elephant population has never recovered from the reduction during the war. The process of catching and training wild elephants is very slow and high mortality rates during this process aggravate the situation. To 1939, there were 6,000 domesticated elephants in Burma, and the average export of teak was 220,092 tons annually. In contrast, in 1965-66, there were only 3,076 elephants, and exports since 1945 have never exceeded 70 per cent of prewar levels (Myint Aung, 1967).

Although teak logs from the natural forests in Burma are most easily transported by floating, there are disadvantages in the procedure. There is a high rate of loss during the initial journey to the rafting station due to logs being either stranded on the stream banks or buried under sands because of floods or in some cases tidal effects. There is also a high rate of loss due to theft. The State Timber Board has tried to salvage stranded logs, but there has been an annual deficit of at least 16,000 logs and usually more; a rate of loss equivalent to between six percent and 29 per cent of the total logs floated each year.

The management procedures for teak production from natural forests are not therefore proving successful.

Ecologically, the Burma selection system appears to reduce the proportion of teak in the forests and speeds the progression towards the teak-less evergreen forest type. The scattered distribution of teak trees and the steep terrain on which they grow make extraction impracticable by mechanized means and depend upon the availability of elephant power and this is presently inadequate. Heavy losses are also incurred in the course of floating the logs to the rafting stations.

3.3 Improvements which could be expected from the use of teak plantations

Prior to 1940, 56,127 hectares of teak plantations had been established in Burma (Blanford, 1956). Almost all these plantings were destroyed by the Japanese during the second world war. A regular planting programme recommenced in 1963, and by 1969, 9,430 hectares of plantation had been established mainly in the M.U.M.D. or L.M.D. forest types, (Office of the Director of Forests, Burma, personal correspondence). The total area suitable for planting teak in Burma has not been surveyed, but there are 230,445 square kilometres of M.U.M.D. and L.M.D. forest types centrally located and available for plantation site selection (see Figure 1). Less desirable, but also a possibility for plantation establishment are the 33,890 square kilometres of D.U.M.D. forest type, and areas of the tropical semi-evergreen forest type (area not available). There would be therefore no difficulties in finding suitable areas for a much expanded plantation programme in Burma.

The use of plantations for teak production would have many advantages compared to the present use of natural forests.

Specifically, there would be substantial improvements in management control, in access, in production levels and in extraction procedures, and potentially in quality control.

Since work in plantation is concentrated, management and the control of operations would be simplified compared to the procedure in natural forests. Plantation sites can be selected so that the topography is not too steep for mechanized operations, and the construction of a network of roads within the plantation would be justifiable. This would facilitate not only a more convenient, but a more intensive degree of forest management.

Production levels would be much higher in a plantation than in a natural forest. As noted above, natural teak forests in Burma are estimated to have a stock of one yield tree in 3.2 hectares, whereas, in plantation, approximately 100 trees per hectare would be left after the final thinnings. Thus, the final yield from plantations, disregarding the yield from thinnings could be much higher than from natural forests even with the use of short rotations, and the exploitation of smaller trees.

With the possibility of construction of a network of roads, and the application of mechanized unit, extraction work could be more efficient in plantation. Use of elephants can be minimised, and extraction of green teak could be economical.

Plantations also permit the immediate application of the results of tree breeding research. Improvement could be anticipated both in production levels and in quality control of the timber produced.

3.4 Disadvantages of teak plantation

The disadvantage of teak plantation can be summarised as:

(i) the reputed production of inferior timber

(ii) the degradation of the site under plantation.

Timber from plantation grown teak has generally been considered inferior to teak of the natural forests (Kadambi, 1945). However, analysis by Nair and Mukerji (1957) in India on plantation and natural grown teak from Burma and different parts of India showed, timber from plantation grown teak (25 - 78 years old) was in no way inferior to naturally grown teak (54 - 264 years old) in mechanical properties (Table 8). Da Costa, et al. (1958) also found no difference between plantation grown and natural teak in mechanical properties, but the details of this study were not specified. These authors also found there were no differences in either decay or termite resistance between plantation grown and naturally grown teak.

Experience in India and Burma has indicated teak plantations can cause serious erosion if an adequate thinning regime is not maintained (Laurie and Griffith, 1942). The particular erosion problem stems from the large size of the teak leaves which can have a surface area as great as 1,300 sq cm (Suri, 1964). These large leaves concentrate rain water which subsequently falls in very large drops. These drops cause serious erosion in plantations lacking sufficient undergrowth to protect the soil (Laurie and Griffith, 1942; Kadambi, 1945; Taggarse, 1945). This is likely to occur

Table 8. Comparison of the mean strength properties of natural and plantation grown teak as given by Nair and Mukerji (1957)

Type of growth	No. of localities	Specific gravity	Rings per inch	Maximum crushing stress lbs/sq. in.	Modulus of rupture lbs/sq. in.	Modulus of elasticity 1000 lbs/sq. in.	Maximum height of drop inches
Natural grown	11	0.575	11.4	5520	11,000	1,520	34.5
Plantation grown	9	0.563	5.8	5680	11,300	1,530	37.5

particularly in sites with steep terrain or in stands which are too densely stocked. The author has also noted such erosion in many teak plantations in Burma which had not been thinned correctly or regularly. Kadambi (1945) notes there was no erosion problem in a well maintained plantation in Mysore (India) due to the presence of good undergrowth. A regular cover of undergrowth is therefore essential in teak plantation, and to ensure this, frequent and regular thinnings are essential.

Thus, although substantial advantages in both production and ease of management are likely with teak plantations, it will be essential for adequate silvicultural procedures to be enforced, otherwise severe erosion could take place.

CHAPTER IV

THE NATURAL DISTRIBUTION OF TEAK AND THE FACTORS AFFECTING THE OCCURRENCE OF THE SPECIES AND THE USE OF THE SPECIES IN PLANTATION

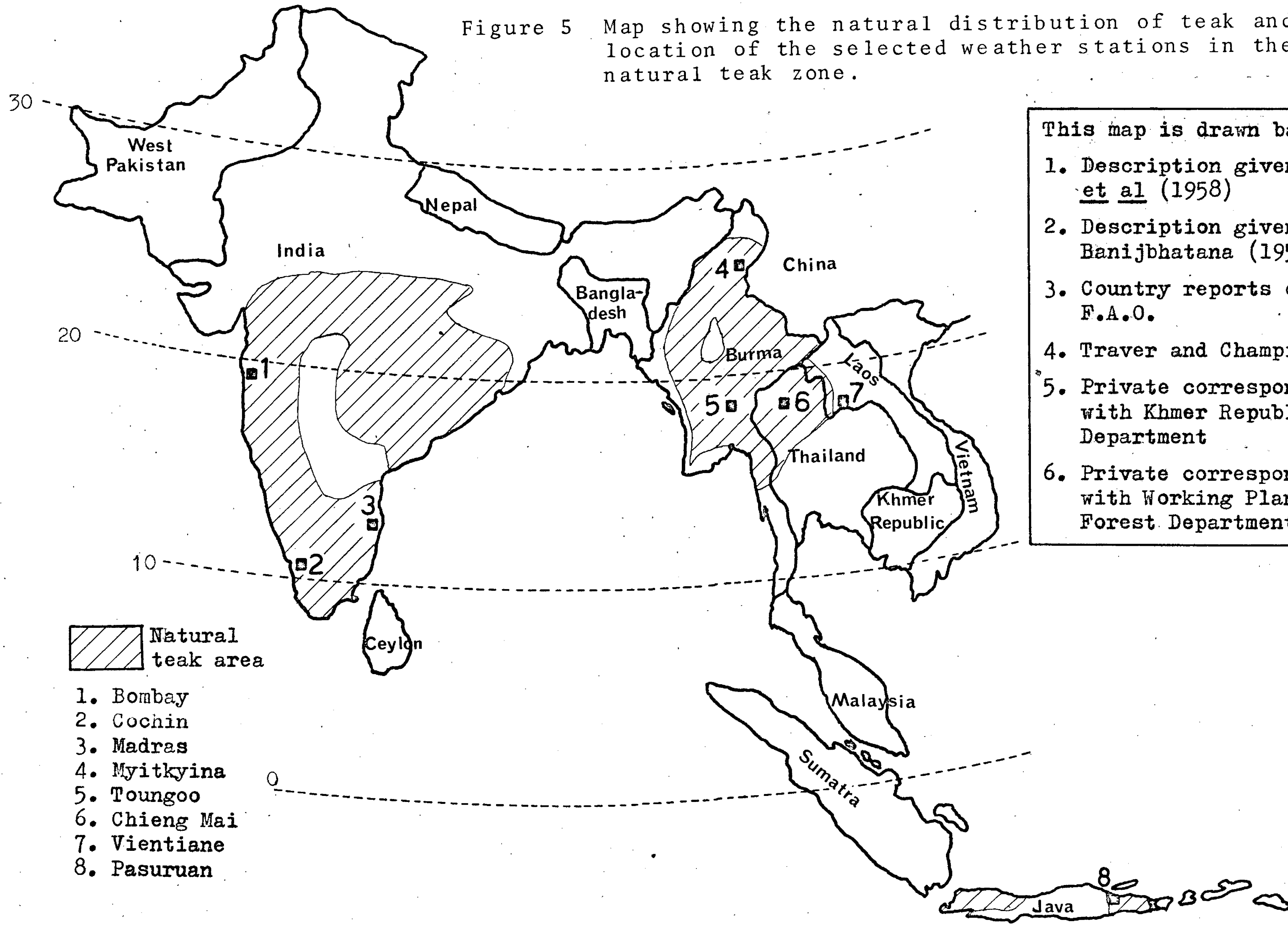
4.1 Natural distribution

The natural distribution of teak (*Tectona grandis* Linn. f.) is not clearly defined. The species is known to be indigenous to the South East Asian countries of Laos, Thailand, Burma, and India (Haig *et al.*, 1958) (Figure 5). But Haig *et al.* consider teak also occurs naturally in the Khmer Republic (Cambodia). However, personal correspondence with the Forestry Department of the Khmer Republic revealed the species does not occur there naturally, but 2,580 hectares have been established in the plantations within the period 1932 to 1969.

The species is also well established in Indonesia on the islands of Java and Muna, but it is not clear whether this occurrence is natural or results from an introduction by the Hindus in the seventh century (Howard, 1948; Letourneux, 1957; van Alphen De Veer, 1957). There is however clear agreement on the presence of teak in Indonesia for some 1,300 years. The area should therefore be considered as an independent seed source, for even if teak was originally introduced to Indonesia, it must now have been sufficiently modified to be regarded as a separate provenance.

The recorded latitudinal limits of the species in the northern hemisphere are between 25°30' N and 10°N (Letourneux, 1957; Kermode, 1964). If the occurrence in Indonesia is natural, the latitudinal limits in the southern

Figure 5 Map showing the natural distribution of teak and the location of the selected weather stations in the natural teak zone.



This map is drawn based on:

1. Description given by Haig <u>et al</u> (1958)
2. Description given by Banijbhatana (1957)
3. Country reports on teak F.A.O.
4. Traver and Champion (1938)
5. Private correspondence with Khmer Republic Forest Department
6. Private correspondence with Working Plans Circle, Forest Department, Burma.

hemisphere would be between 5°S and 9°S. The distribution pattern is discontinuous (Trevor and Champion, 1938), and occurrences are limited to regions with an altitude of 914 metres or less (Stamp, 1925).

As already has been discussed under Chapter II, the species occurs primarily in the mixed deciduous forest type, but it is also found in the semi-evergreen and the deciduous dipterocarp forests. This is true for all the countries where teak occurs naturally, and the occurrence of these forest types is widespread (Haig et al., 1958).

4.2 Climatic requirements

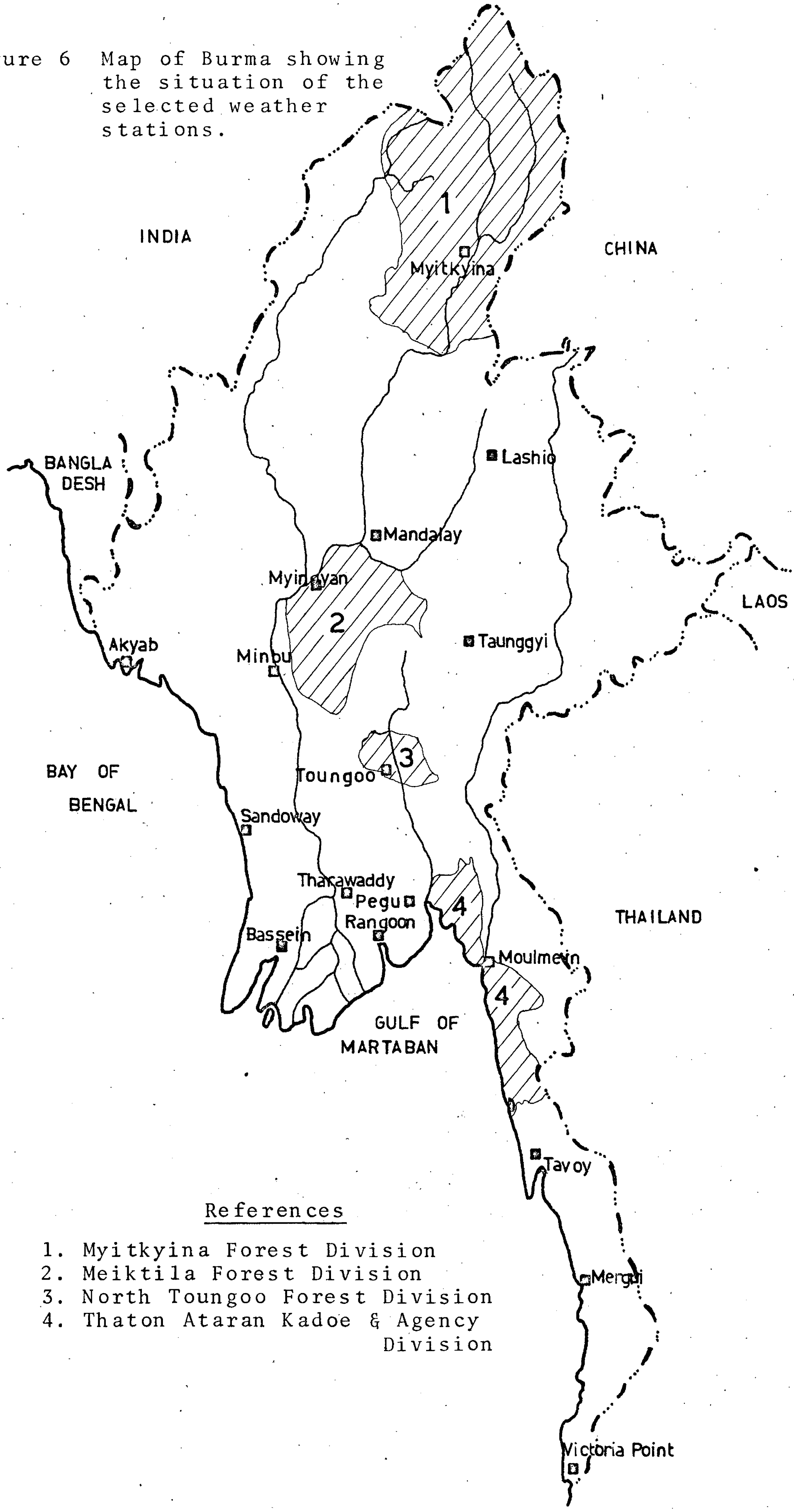
4.2.1 Rainfall

Growth, development, and quality of teak is to a great extent determined by the amount and distribution of rainfall (Bellouard, 1956; Mensbruge, 1956; Haig et al., 1958; Kermode, 1964).

The species grows well in warm, moist, tropical regions with an annual rainfall within the range 1,270 mm to 3,810 mm (Haig et al., 1958). But the species does occur in areas with rainfall as low as 760 mm, as for example in parts of Meiktila Forest Division in Burma (Figure 6). In these areas, it is normally stunted and crooked, and of very poor quality (Stamp, 1925; Haig et al., 1958). The author has observed teak trees in such low rainfall areas to have a maximum height of only eight or nine metres.

The region with the highest rainfall in which teak occurs naturally in Burma is the Thaton/Ataran/Kadoe and Agency Division (Figure 6.). This region has an annual

Figure 6 Map of Burma showing the situation of the selected weather stations.



References

1. Myitkyina Forest Division
2. Meiktila Forest Division
3. North Toungoo Forest Division
4. Thaton Ataran Kadoe & Agency Division

Table 10. Mean monthly temperature for selected stations in the natural teak zone

Location	Latitude	Altitude (metres)	Mean monthly temperature (°C)												Mean annual temperature
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	
India															
Bombay	18°54'N	11	24	24	26	28	30	29	27	27	27	28	27	26	27
Madras	13°04'N	16	24	26	28	31	33	33	31	31	30	28	26	25	29
Cochin	9°58'N	3	27	28	29	30	29	26	26	26	26	27	28	27	27
Burma															
Myitkyina	25°23'N	145	17	19	23	26	28	27	27	27	28	25	22	18	24
Toungoo	18°56'N	48	22	24	29	31	30	28	27	27	28	28	26	22	27
Thailand															
Chieng Mai	18°47'N	314	21	23	26	29	29	28	27	27	27	26	24	21	26
Laos															
Vientiane	17°58'N	162	21	24	26	28	28	28	27	28	27	26	24	22	26
Indonesia															
Pasuruan	7°38'S	5	27	27	27	27	27	26	26	26	27	28	28	27	27

Source - Tables of Temperature, Relative Humidity and Precipitation for the World, Part V, Asia.

Table 10. Mean monthly temperature for selected stations in the natural teak zone

Location	Latitude	Altitude (metres)	Mean monthly temperature (°C)												Mean annual temperature
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	
India															
Bombay	18°54'N	11	24	24	26	28	30	29	27	27	27	28	27	26	27
Madras	13°04'N	16	24	26	28	31	33	33	31	31	30	28	26	25	29
Cochin	9°58'N	3	27	28	29	30	29	26	26	26	26	27	28	27	27
Burma															
Myitkyina	25°23'N	145	17	19	23	26	28	27	27	27	28	25	22	18	24
Toungoo	18°56'N	48	22	24	29	31	30	28	27	27	28	28	26	22	27
Thailand															
Chieng Mai	18°47'N	314	21	23	26	29	29	28	27	27	27	26	24	21	26
Laos															
Vientiane	17°58'N	162	21	24	26	28	28	28	27	28	27	26	24	22	26
Indonesia															
Pasuruan	7°38'S	5	27	27	27	27	27	26	26	26	27	28	28	27	27

Source - Tables of Temperature, Relative Humidity and Precipitation for the World, Part V, Asia.

Figure 7.1 Climograms showing the intensity and distribution of monthly rainfall and monthly temperature of four selected stations in the natural teak zone.

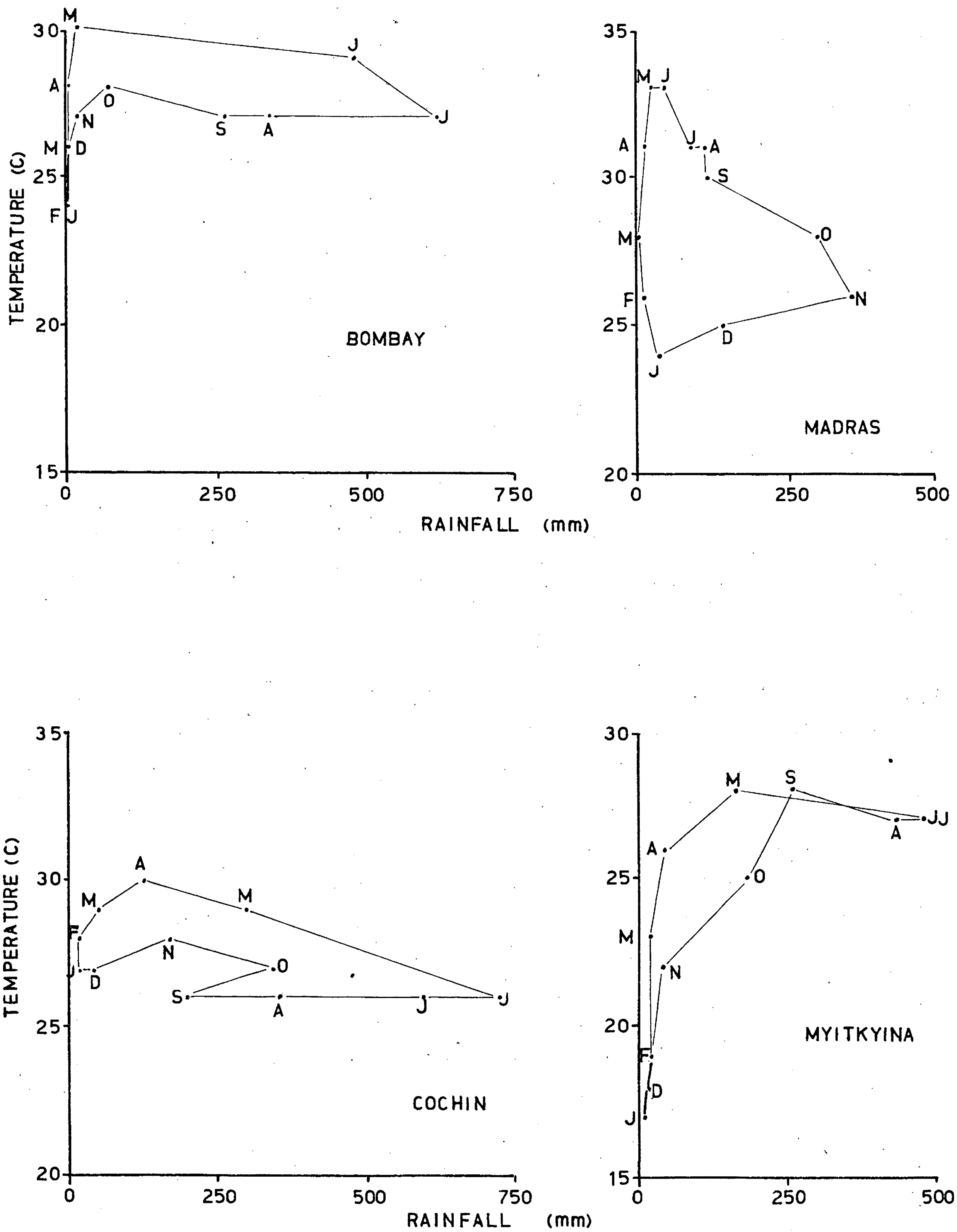
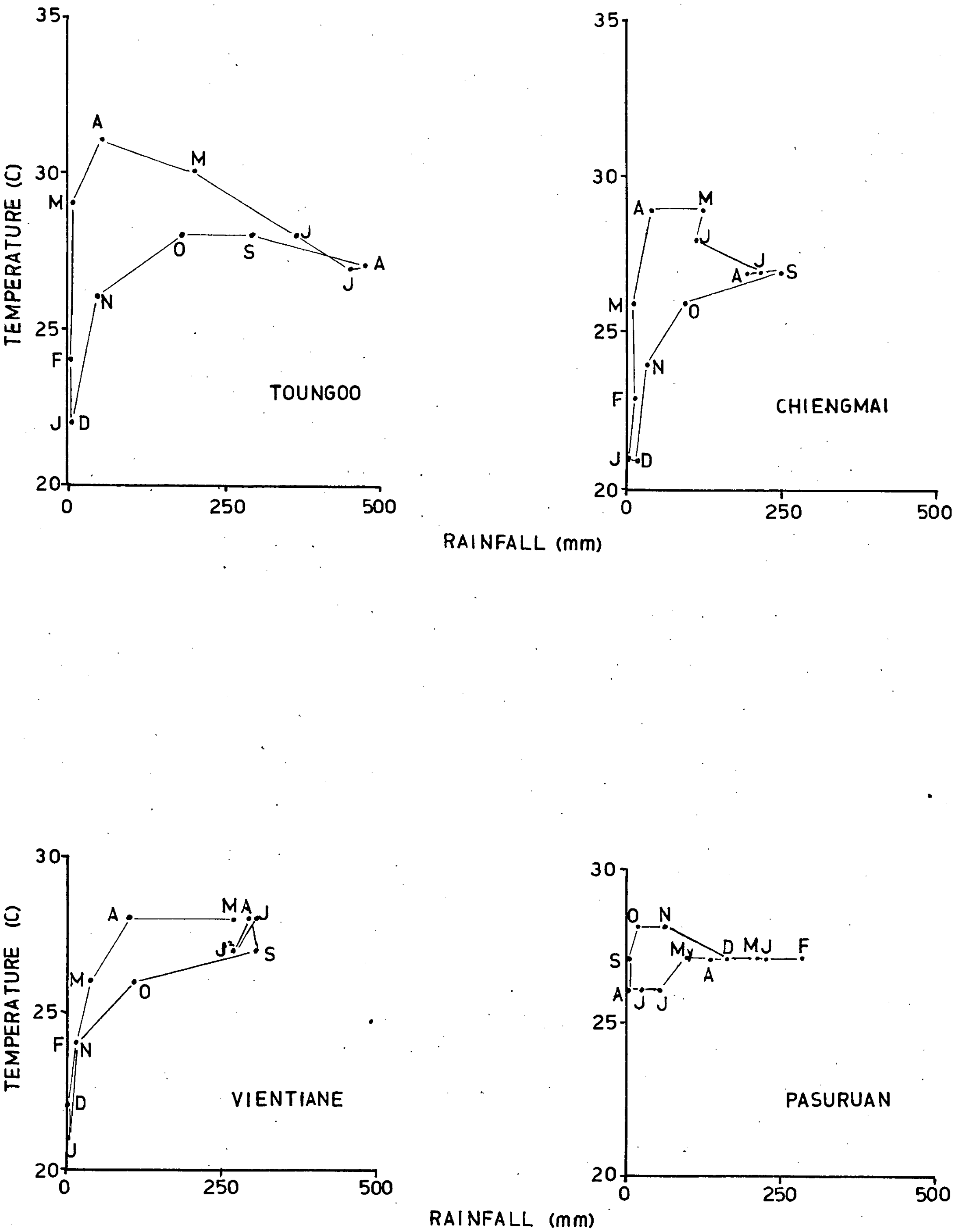


Figure 7.2 Climograms showing the intensity and distribution of monthly rainfall and monthly temperature of four selected stations in the natural teak zone.



rainfall (ranges between 1,079 mm to 2,931 mm). However, the one feature common to all is the presence of a definite dry season of two months or more.

A dry period of several weeks is known to be deleterious to teak seedlings but not to established trees (Kermode, 1957, 1964; Haig et al., 1958). It is therefore important for seedlings to be well established prior to the commencement of a dry period. This suggests a need for a reliable and consistent rainfall during the growing season, especially during the first year of establishment. Consequently, teak might be expected to be unsuited to areas subject to sporadic drought in what was normally a wet season. Plantation establishment in such conditions would appear to be liable to failure.

Topography and rainfall interact in determining the performance of teak. Normally, on dry hill tops, ridges, and upper slopes, teak grows better on the cooler northern and eastern aspects rather than on the hot southern and western aspects (Griffith and Gupta, 1947; Kulkarni, 1951). However, in heavy rainfall areas, teak prefers the warmer southern and western aspects, while the cooler northern and eastern aspects are occupied by wetter evergreen forests.

4.2.2 Temperature

No detailed studies have been made on the temperature requirement of teak although the species has an extensive distribution through areas with markedly varying temperature regimes (Table 10, Figure 7.1 and 7.2). This suggests tolerance of a wide range of temperatures. Haig et al. (1958) recorded the shade temperature of the regions where teak grows best as between 12.5°C and 40°C, but noted the species will survive within the temperature extremes of 2°C and 46°C. 'Shade temperature' was not defined by these authors, but is presumed to be similar to that recorded behind a Stevenson screen. These figures are supported by the detailed temperature ranges of the localities within the natural teak zone given in Figures 7 and 8.

The species is also known to be severely cut back by frost (Stamp, 1925; Takle and Mujumdar, 1957; Haig et al., 1958; Kermode, 1964). This agrees with the species' altitudinal limit (914 m) which is also considered as the frost line in Burma (Stamp, 1925). However, Kadambi (1957) notes that frosts rarely killed trees in the frosty area of India. In these frosted areas, seedlings were regularly cut back until they were above the frosted levels after which they developed normally. However, the intensity and duration of the frost referred to by Kadambi are not recorded, but a need for care is indicated in the establishment of teak in frosty areas.

There are no other reports of the importance of temperature for teak development and this suggests the species may be tolerant of a wide range of temperatures. However, with the increasing interest in plantations and the exchange of seeds between localities which may have widely differing temperature regimes, it would appear important to determine the temperature sensitivity of teak provenances. Any provenance shown to be restricted to a limited temperature range would not then be used outside that range.

4.2.3. Daylength

No studies of the effects of changing daylength on the development or growth of teak have been recorded. Because of the small variation in the daylength in the tropics, botanists have assumed that tropical species are not markedly affected by daylength fluctuation (Lowe, 1968). However, the work of Njoku (1964) on *Hildegardia barteri* (Mast) Kostern. in Nigeria and that of Piringer *et al.*, (1958) on *Rauvolfia vomitoria* Afzel. in tropical Africa suggests that this may not be a well founded assumption, and daylength may be a more important factor of the environment in the tropical regions than is generally realized. Cacao and several other tropical species react to variation in daylength in the same way as temperate plants in so far as the vegetative growth is concerned. As the latitude increases north or south of the equator, this response of tropical plants to daylength variation becomes more pronounced (Alvim, 1964).

Teak is known to respond to light intensity. Bhatnagar (1966) grew teak seedlings under 9 per cent, 22 per cent, 94 per cent and 100 per cent of natural light intensity. When measured, he found that there was direct correlation between total plant dry weight and height growth, and height growth was greatest at 94 per cent (14.3 cm). This was followed by 100 per cent (13.0 cm), 22 per cent (10.8 cm), and 9 per cent (7.8 cm) respectively. This seems to indicate that although the species demands high light intensity, it does need some shading in the seedling stage. Similarly, Kadambi (1957), and Takle and Mujumdar (1957) also noted that although teak is strongly light demanding, seedlings do benefit from moderate shade.

4.2.4 Climatic conditions of Burma

The climate in Burma is characterized by definite wet and dry seasons. The wet season occurs during summer (June - October), and the dry season during the winter (November - May).

Climatic data for a few selected localities approximately representative of most areas of the country are presented in Tables 11 and 12 and Figures 8.1 to 8.5. (See also Figure 6). Of these, Myitkyina, Toungoo, and Tharawaddy represent areas carrying good natural teak forests, Akyab, Sandoway, and Tavoy represent areas with tropical evergreen forests, and Myingyan and Minbu represent the dry zone of Central Burma.

Most areas of Burma have a rainfall pattern determined by two monsoonal influences (Nuttonson, 1963). All have a dry period from November through to April when the country is affected by the north-east monsoon. This blows from the continental land mass of East Asia and brings dry and cold conditions. For the remainder of the year the south-west monsoon prevails. This brings moisture laden air masses to the country from the Indian Ocean. Areas in the coastal strips (Akyab, Sandoway, Tavoy, Victoria Point) receive very heavy rainfall in this period, but areas inland (Mandalay, Myingyan, Minbu) lie in a rain shadow area behind a mountain range (Arakan Yoma), (see Figure 1 for location), and receive appreciably less.

Thus, although the rainfall varies considerably throughout the country much of the area is within the rainfall range specified above as suitable for the occurrence

Table 11. Monthly rainfall distribution for selected stations in Burma

Location	Latitude	Altitude (metres)	Mean monthly rainfall (mm)												Mean annual rainfall
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Myitkyina	25°23'N	145	10	23	23	46	160	480	478	434	257	183	38	13	2145
Lashio	22°56'N	854	5	10	13	56	170	257	297	325	201	142	74	23	1573
Mandalay	21°59'N	77	*	5	5	36	150	152	74	102	147	127	64	10	872
Myingyan	21°28'N	61	*	3	3	8	84	74	81	112	150	81	28	5	629
Taunggyi	20°47'N	1524	*	10	3	33	249	198	287	330	216	173	38	15	1552
Minbu	20°11'N	50	*	3	5	20	137	152	112	119	157	112	58	10	885
Akyab	20°08'N	9	3	5	10	51	391	1151	1400	1133	577	284	130	20	5155
Toungoo	18°56'N	48	5	5	8	53	203	366	455	480	297	183	48	10	2113
Sandoway	18°28'N	9	3	3	*	48	414	1209	1684	1222	665	287	69	18	5622
Tharawaddy	17°39'N	15	3	5	15	36	236	437	533	419	295	122	71	41	2213
Rangoon	16°47'N	5	3	5	8	51	307	483	582	528	394	180	69	10	2620
Bassein	16°47'N	6	3	5	5	3	244	584	638	602	376	193	79	13	2745
Moulmein	16°30'N	23	8	5	10	76	516	904	1176	1102	714	216	53	3	4783
Tavoy	14°05'N	6	5	13	43	79	561	1151	1270	1186	818	262	61	8	5457
Victoria Point	9°59'N	48	10	18	56	130	503	719	732	663	711	447	160	58	4207

* = less than 1.3 mm

Source - Nuttonson (1963).

Table 12. Mean monthly temperature for selected stations in Burma

Location	Latitude	Altitude (metres)	Mean monthly temperature (°C) Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean annual temperature
Myitkyina	25°23'N	145	17	19	23	26	28	27	27	27	28	25	22	18	24
Lashio	22°56'N	854	15	17	21	24	25	25	25	24	24	23	19	16	22
Mandalay	21°59'N	77	20	23	28	31	31	30	30	29	29	27	24	20	27
Myingyan	21°28'N	61	21	24	28	32	31	30	29	29	29	28	25	21	27
Taunggyi	20°47'N	1524	14	16	20	23	22	21	21	21	21	20	17	14	19
Minbu	20°11'N	50	21	24	29	32	32	29	29	29	29	28	25	22	27
Akyab	20°08'N	9	21	22	26	28	29	28	27	27	28	27	25	22	26
Toungoo	18°56'N	48	22	24	29	31	30	28	27	27	28	28	26	22	27
Sandoway	18°28'N	9	21	22	25	28	29	27	27	27	27	27	26	23	26
Tharawaddy	17°39'N	15	23	25	28	31	30	28	27	27	28	28	26	23	27
Rangoon	16°47'N	5	25	26	29	30	29	27	27	27	27	28	27	25	27
Bassein	16°47'N	6	24	25	28	30	29	28	27	27	27	28	26	24	27
Moulmein	16°30'N	23	25	27	29	30	28	27	26	26	27	27	27	25	27
Tavoy	14°05'N	6	25	26	28	29	28	26	26	26	26	27	26	25	27
Victoria Point	9°59'N	48	27	27	28	29	27	26	26	26	26	26	26	26	27

Source - Nuttonson (1963).

Figure 8.1 Climograms showing the intensity and distribution of monthly rainfall and monthly temperature of four selected stations in Burma.

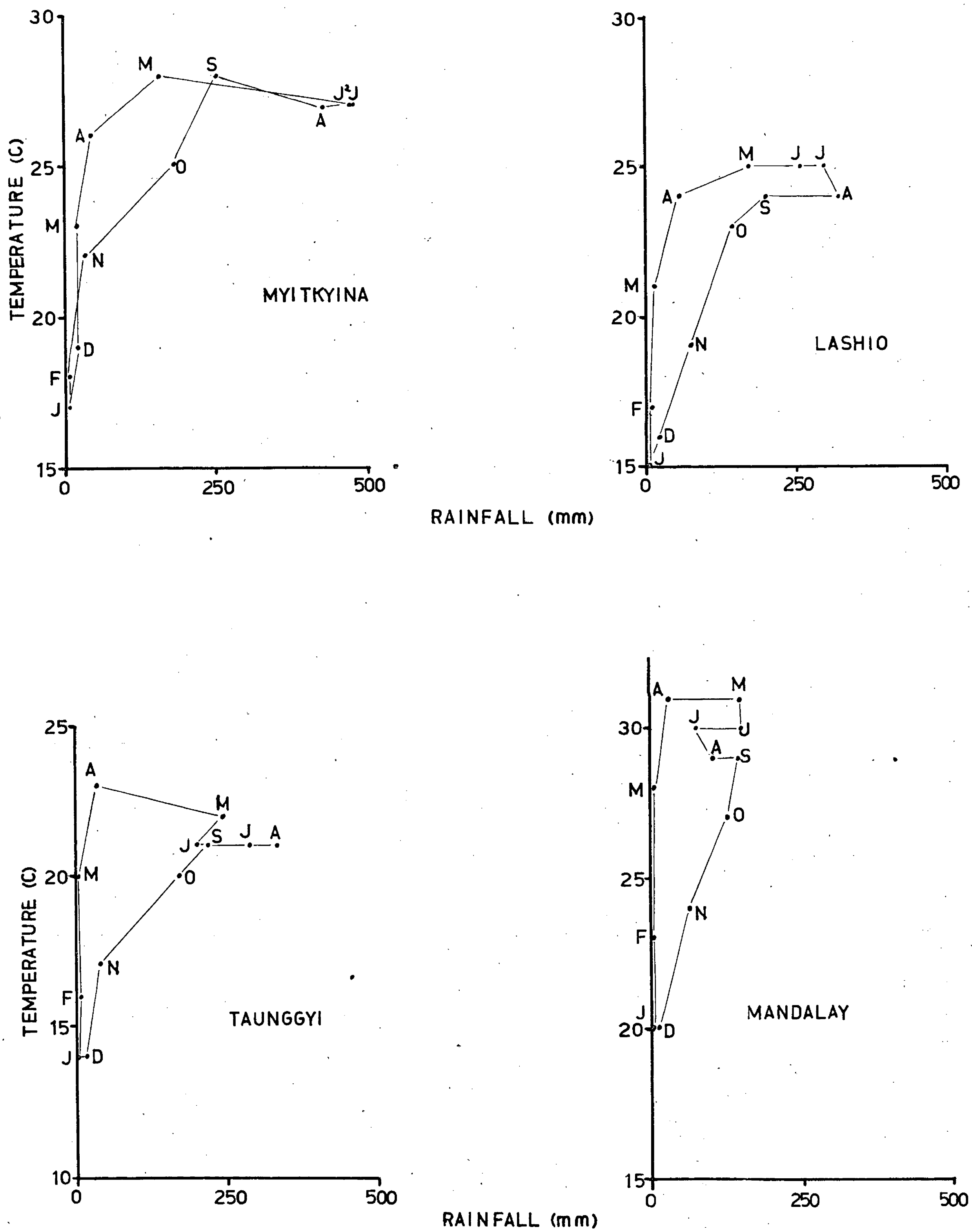


Figure 8.2 Climograms showing the intensity and distribution of monthly rainfall and monthly temperature of four selected stations in Burma.

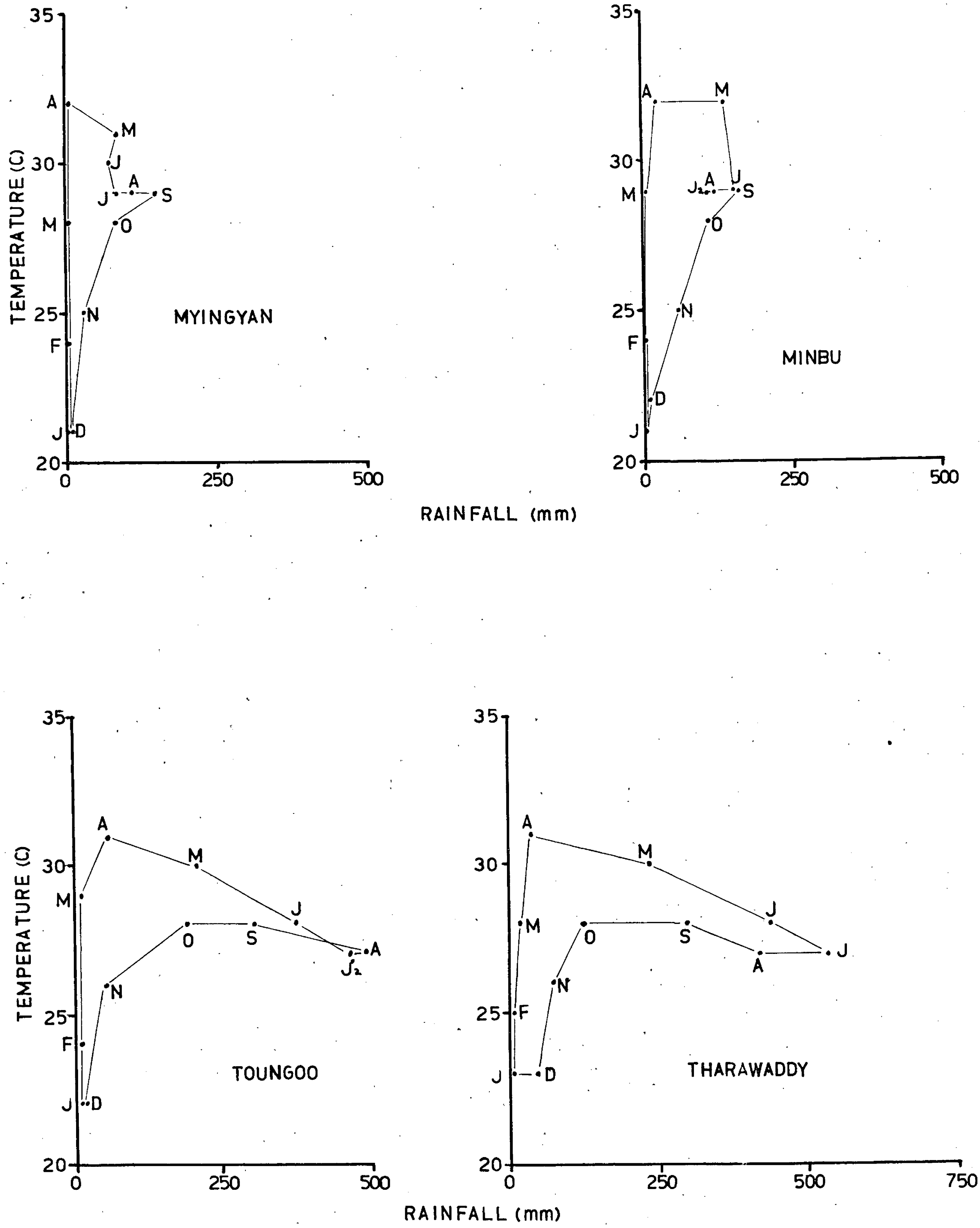


Figure 8.3 Climograms showing the intensity and distribution of monthly rainfall and monthly temperature of two selected stations in Burma.

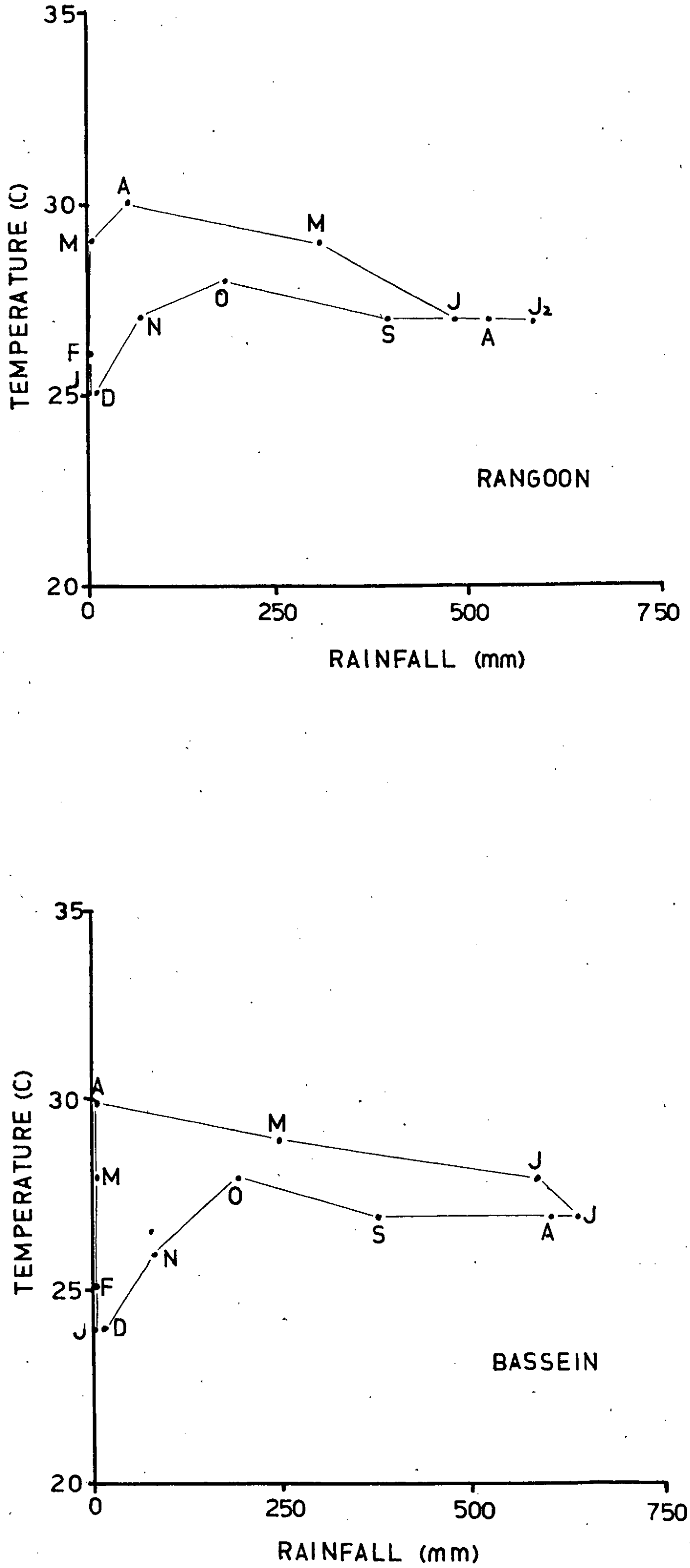


Figure 8.4 Climograms showing the intensity and distribution of monthly rainfall and monthly temperature of two selected stations in Burma.

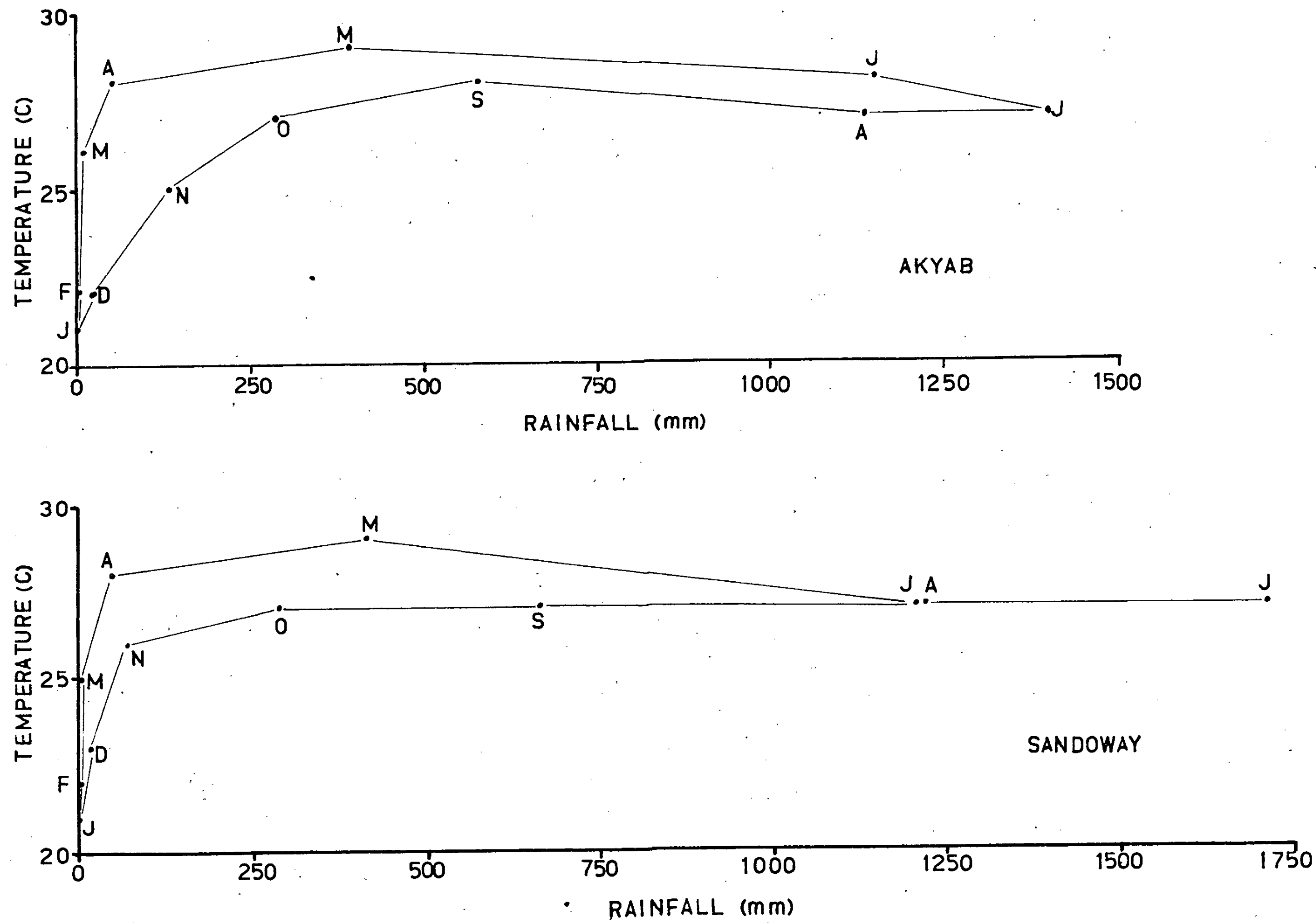
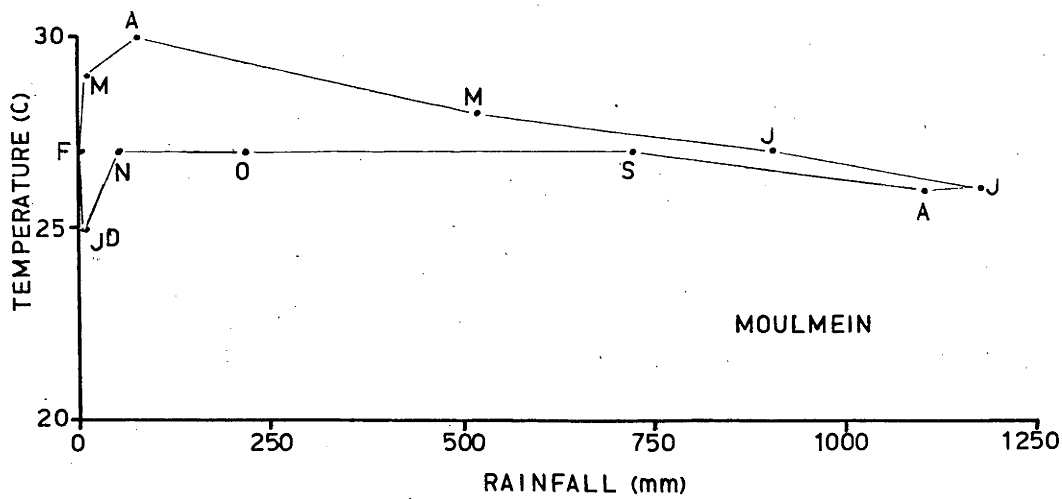
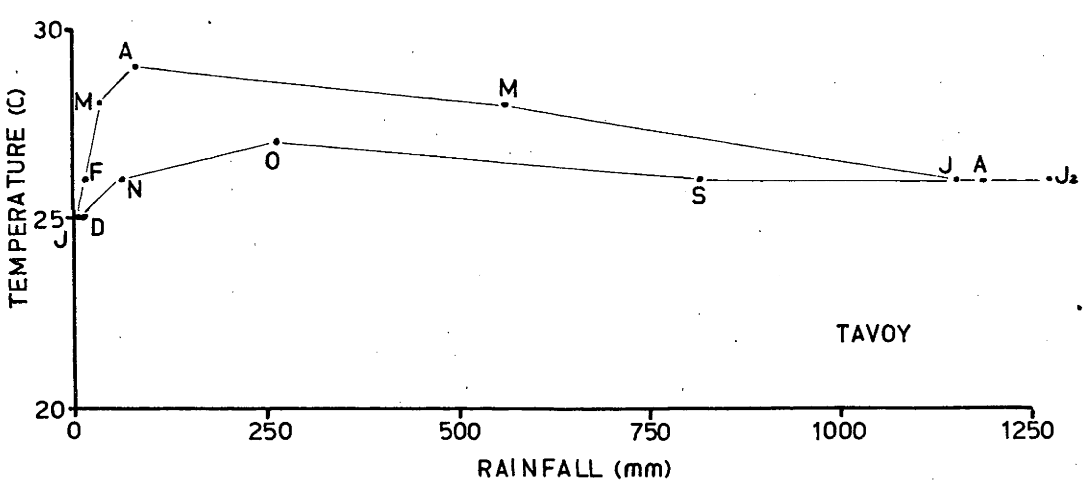
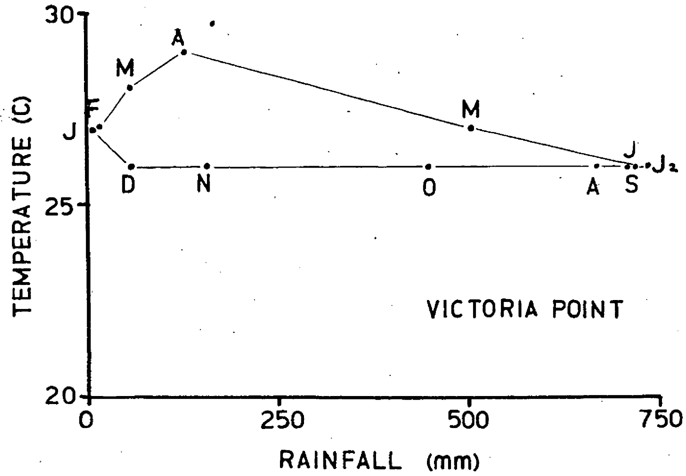


Figure 8.5 Climograms showing the intensity and distribution of monthly rainfall and monthly temperature of three selected stations in Burma.







of natural teak forests (1,270 mm - 3,810 mm). Moreover, most areas also have the necessary dry season.

Besides a common rainfall pattern, there is also a common temperature pattern for most of the country. The coolest months are December, January, and February, during which the mean monthly temperature is approximately 15°C for the hilly regions (Myitkyina, Lashio, Taunggyi), and 23°C for the lowland areas. The hottest months are generally April and May when mean monthly temperatures are approximately 32°C in the central dry zone (Mandalay, Myingyan, Minbu), 30°C in the lowlands (Toungoo, Tharawaddy, Rangoon, Moulmein, Bassein, Akyab, Sandoway, Tavoy, Victoria Point), and 25°C on the highlands (Myitkyina, Lashio, Taunggyi).

The overall annual temperature range in a particular locality decreases with latitude. In areas north of Rangoon, the range of mean monthly temperatures is approximately 15° - 25°C (10°C difference) in the hilly regions and approximately 23°C - 31°C (8°C difference) in the lowlands. In Rangoon and southern regions, however, the same temperature range is approximately 25° - 30°C (5°C difference) and at the furthest locality south (Victoria Point) is only 27°C - 29°C (2°C difference). Daily temperature ranges follow a similar pattern and the temperature thus becomes more equable towards the equator.

4.3 Edaphic requirement

4.3.1 Geology

Several authors have tried to correlate the occurrence of teak with the underlying parent materials (Vahid, 1927;

Kadambi, 1951; Kulkarni, 1951; Sathe, 1951). Sathe (1951) reviewing the role of geology in the distribution of plant communities pointed out that plant life is mainly controlled by soil and water. Soil is directly related to the surface geology, and retention of soil moisture is to a great extent determined by local and regional geology. Sathe reasoned therefore that the underlying geological material was most important in determining the distribution of plant communities. Other authors have however qualified the importance of geological formations in determining the occurrence of natural teak forests.

Teak is recorded as occurring on a wide variety of geological formations and rock types. These include limestone, granite, gneiss, schist, sandstone, conglomerate, shale and the igneous Deccan trap, the major Indian rock formation associated with teak (Kulkarni, 1951; Puri, 1951; Banijbhatana, 1957; Seth and Yadav, 1957; Takle and Mujumdar, 1957; Haig et al., 1958). However, whilst teak does occur on soils overlying conglomerate, sandstone or laterite, it will not grow well in such localities. Indeed, it may be absent from such soils (Kadambi, 1957; Seth and Yadav, 1957; Takle and Mujumdar, 1957).

In the State of Madhya pradesh, India, Kulkarni (1951) surveyed approximately 3,890 square kilometres of forests and the geology of the region by complete enumeration using random sample plots, one acre in size and distributed throughout the area. At each plot location, records were made of the forest composition, the local geology, altitude, topography, rainfall and the temperature regime; any modifying effects due to interference by man, grazing, or fire were also recorded. No correlation could be established between the existence of teak and altitude, topography, rainfall, or temperature. Unfortunately, the methods by which correlations were attempted were not defined. The range of altitudes sampled, and the rainfall and temperature regimes were all within those noted above as suitable for the occurrence of teak and this may explain why correlation patterns could not be established linking these features with the occurrence of teak. More importantly, however, kulkarni was able to demonstrate a relationship between the geological formations and the occurrence of teak (Table 13). Further support was given when the same overall pattern was found in both the geological map of the local area and forest stock map, these having been prepared by different government agencies at different times. Although Kulkarni admitted the relationship was purely qualitative and applicable only to the region studied, in the North Chanda Division in India, Vahid (1927) observed teak to be present whenever the geological conditions were favourable, and felt that where teak did not occur, the geology of the locality must be unsuitable. Also in Mysore, India, Kadambi (1951) found that changes in the parent rock caused marked changes in the occurrence and growth of teak, adding further support to the work of Kulkarni and Vahid.

Table 13. Effect of geological formation on the distribution of teak as given by Kulkarni (1951)

Geological formation	Percentage of teak within the forest composition
Deccan trap	80
Granite gneisses	75
Calcarious crystalline rock	60
Phylites and schists	50
Bagra conglomerate	45
Jabalpur conglomerate and haematite	15
Talchirs and Barakars (sandstone)	8
Bijoris (sandstone)	3
Pachmarki sandstone	0
Denwa sandstone	0
Jabalpur sandstone	0

Other workers however believe such relationships between the underlying rock formation and the distribution of teak are oversimplifications. Takle and Mujumdar (1957) felt climate, altitude, and biotic factors to be more important, since these factors modified the effects of the parent rock and determined the physico-chemical properties of the soil formed from it. Gupta (1957), similarly felt the application of geological generalization to areas where weathering conditions were intense was questionable. In his opinion, strict adherence to geological formations to determine the distribution of teak leads to false conclusions. Gupta was supported by a report by Kadambi (1957) who showed that although teak generally avoids laterite, a red loam formed from a completely weathered laterite has been found suitable for natural regeneration of the species.

Thus broad generalization between geological formation and teak occurrence is clearly possible in some areas of India, and some parent materials clearly limit teak occurrence. However, care should be taken in applying the generalization, for the effect of the underlying materials can be modified by climatic and biotic factors, particularly where weathering is intense.

4.3.2 Soil

Soil factors known to affect the growth of teak are moisture status, soil depth, structure, texture, and fertility both of surface and sub-surface soils. Soil pH was also believed to affect the growth of teak, but there are contradictory ideas and this needs further confirmation.

The best teak tends to develop in deep well drained alluvium found along the banks of the rivers (Griffith and Gupta, 1947; Seth and Yadav, 1957; Takle and Mujumdar, 1957). In agreement with the above, the author has also observed teak plantations in Burma to be of high quality on alluvium along the banks of streams, but the quality deteriorated up slope where stagheaded or dead trees frequently occurred. In the natural forests of Burma, growth of teak is noticeably more vigorous at the foot of the ridges than on top. Griffith and Gupta (1947) observed the same in India. Relationship between teak distribution and soil moisture has also been recorded by Champion (1938), who found teak forests in India and Burma were associated with the moister soils.

Teak will not tolerate water logging or stiff clayey soils (Bhatia 1954; Kadambi, 1957; Takle and Mujumdar, 1957;

Stevens, 1970). Kadambi noted under conditions of water logging or stiff clay soil, teak was replaced by *Anogeissus latifolia* Wall. Similarly, Griffith and Gupta (1947) found a low SiO_2/R_2O_3 ratio, a low dispersion coefficient and an unusually low or unusually high water table were all unfavourable for the growth of teak.

The species is also reported as avoiding soils liable to drought (Bhatia, 1954; Kermode, 1957, 1964; Haig *et al.*, 1958; Stevens, 1970), but no detailed studies on reports are available.

There are contradictions in the report of the soil pH level preferred by teak. According to the report from India included in the F.A.O.'s 'Country Report on Teak' (Anon, 1956), teak usually occurs on soil with a pH within the range of 6.5 - 7.5. Below pH 6.0, teak was completely absent and above pH 8.5, growth was poor. This was supported by Kulkarni's (1951) work in the Hoshangabad division in India. However, Gupta (1951) found that soils in site quality II and III of teak plantation in Nilambur, India, had pH value ranging between 5.5 - 5.8, which is well below the limits set by Kulkarni. Similarly, Stevens, (1970) in a soil survey of teak plantations in Laos showed almost all soils studied had a pH of 4.0 - 6.0. In many instances, plots with high site quality had a soil pH of 5.5 - 6.5 whilst plots on low quality sites generally had a very acidic pH. Stevens concluded there appears to be no highly correlated positive relationship between rate of teak growth and neutral or slightly acid soil pH. Although Steven's and Gupta's reports on pH value covered only teak plantation soil, there is clearly some confusion and more work needs to be done before definite conclusions can be drawn on limitations of the occurrence and growth of teak by pH values.

Several studies have indicated a relationship between soil calcium and the occurrence and growth of teak (Kadambi, 1951; Kulkarni, 1951; Puri, 1951). In India, Kadambi (1937) examined soil samples from the central and southern portion of Muthodi State forests which supported high quality teak forest and the northern portion of the same forest which was altogether teakless. The results revealed lime as present in very small amounts (unspecified) in the soil of the former and as absent in those of the latter, otherwise the soils appeared similar in all respects. Puri and Gupta (1950) using foliar calcium analysis in India showed teak has a much higher demand for soil calcium than did sal (Shorea robusta Gaertn. f.).

However, Laurie (1931) analysed the soils of two apparently identical areas in the Palakadon valley in Madras, one of which contained an excellent growth of teak and the other none. He found both areas had poor lime status. Laurie also observed no difference in respect of some elements (CaO, P_2O_5, K_2O) or pH, and concluded that lime in itself was not necessarily a vital factor in determining the existence of teak. Bhatia (1955) attempting to explain Laurie's results, perhaps rather optimistically suggested the deficiency of lime in the teak area could have developed as a result of depletion under continuous teak growth. He suggested the area was approaching the seral stages in which teak would be replaced by other species. Care should therefore clearly be exercised in planting in areas lacking lime, but it appears successful growth could be possible in such sites.

The soil factors affecting teak growth appear therefore to vary with location. Generalizations developed for a particular region may not be valid elsewhere. In summary, teak appears to prefer moderately acid soil and relatively high calcium levels, but an absence of these factors will not necessarily preclude satisfactory teak growth. Stevens (1970) has perhaps summarized the position most satisfactorily. Considering areas for teak plantations in Laos he felt that to look at certain rock types, high soil calcium, or acidity as the sole determinants of the potential growth of teak was too simple a view of a complex situation. He instead summarized the most satisfactory soil type for teak plantation as a deep, porous, friable, sandy or silty clay loam with well developed structure.

4.4 Fire and succession of teak forests

In the higher rainfall areas in which teak is found naturally, the successional trend of moist deciduous forests is often towards a still moister type of semi-evergreen and evergreen climax (Kermode, 1957, 1964; Takle and Mujumdar, 1957; Haig, *et al.*, 1958). Most species in the mixed deciduous forests are unable to regenerate under their own shade as they are light demanders, while the majority of the evergreen species, being shade bearers survive being shaded (Aung Din, 1951). Consequently in an undisturbed condition, teak and other light demanding species are gradually replaced by the shade bearing evergreen species (Haig, *et al.*, 1958).

Fire checks the progress in teak forests to the evergreen type (Aung Din, 1951; Kermode 1957, 1964; Haig et al., 1958). Young teak advance growth as well as a few numbers of associated species in the deciduous forests can withstand burning back year after year (Kermode, 1957, 1964). Under favourable conditions this advance growth can send up vigorous shoots to sufficient height to escape from the danger of light ground fire and become established (Kermode, 1964). Excessive fire will, however, lead to the regression from mixed deciduous teak forests to open savannah type of vegetation with dense grass (Takle and mujumdar, 1957).

Conversely, complete fire protection encourages a rank growth of bamboos and other evergreen and shade bearing fire tender deciduous species. These replace teak and accelerate the successional trend to the evergreen climax (Haig, et al., 1958). Great stress was laid on the necessity for fire protection during the early days of forest conservation in Burma. In Pegu Yoma (see Figure 1 for location) alone, 8,104 square kilometres was fire protected (Aung Din, 1956). However, observations and experiments proved the practice to be deleterious to teak as it encouraged the development of fire tender evergreen species and was thus abandoned (Aung Din, 1956; Kermode, 1964).

4.5 Man and forest management

Teak forests in Burma are managed under the Burma Selection System. This is discussed in detail under Chapter III. Briefly, it involves exploitation of all teak trees that have attained the prescribed girth limit, and improvement fellings. In these improvement fellings, any tree regardless of species crowding or over shadowing future yield teak trees is removed. Only teak is exploited from the more inaccessible areas which form the greatest part of the forest, but other hardwoods are extracted from areas with ready access.

Experience in Burma suggests these operations have benefited only existing saplings for further growth and development, and the stimulation of fresh regeneration is doubtful (Haig et al., 1958). The long term future for teak in natural forests managed in this way must therefore be doubtful.

Shifting cultivation also disturbs the trend of succession in these forests. This form of cultivation is practised by nomadic Burmese hill tribes who clear a forest area and put it under cultivation for only one year. The area is then abandoned to revert to forest. According to Kermode (1964), such practices in the Burmese tropical semi-evergreen forests often cause the forest to revert to pre-climax condition, and early colonizers, such as Kywesa (Trema amboinensis Blume) tend to develop. Teak does not usually reappear under these conditions. However, in the drier deciduous forests where advance growth of teak and other deciduous species is usually present in abundance, the area normally regenerates to its original state after shifting cultivation. The author has observed a fairly high proportion of teak saplings in areas abandoned by shifting cultivators on the Pegu Yoma (Figure 1) in Burma. Thus, the disturbances by man if properly studied and applied can be constructive rather than destructive to teak forest.

4.6 Conclusion

In summary, teak which is widely distributed in South East Asia is a species which is tolerant of a very wide range of climatic and edaphic conditions. However, the species does not occur in regions lacking a definite dry season or where the rainfall is outside the range 760 mm - 5,080 mm. The species altitudinal limit (914 metres) is probably associated with sensitivity to frost. Teak will tolerate a wide range of geological formations, tending to avoid sandstones and conglomerates. The species also avoids stiff clayey and lateritic soils, and areas subjected to inundation or to severe drought. Most of the moist teak forests can be considered as in seral stage progressing towards an evergreen climax. This progression may be interrupted in many ways including fire or shifting cultivations. These disturbances, if properly manipulated can be used to check the progression and maintain the teak forest. Unfortunately, the management technique applied in many natural forests may be reducing the teak resource.

One area in which little information is available is a knowledge of the effect of temperature and daylength in teak performance. Such knowledge will bring better understanding of the factors affecting growth and occurrence of the species which is of vital importance for safe and correct allocation of areas to teak plantation.

4.6.1 Site selection for teak plantations

Although teak appears tolerant of a wide range of climatic and edaphic conditions, it is clear that relationship between specific conditions and teak growth may be complex. Care is therefore needed in the selection of sites for plantations.

In areas where teak occurs naturally, site selection is facilitated by correlation with the existing forests. Thus, for example in Burma, site selection for teak plantation is most easily achieved by choosing areas with a good growth of Bambusa polymorpha and Cephalostachyum pergracile, where the topography is not steep, and where adequate fuel for a ground fire is present.

In the absence of vegetational indicators, site selection is effected according to the ecological requirements of the species as follows:-

(1) Sites which are flat or having only slightly sloping or an undulating topography should be selected. Steep gradients should be avoided.

(ii) Dry hill tops, ridges and upper slopes should not be used. If a drier site situated on hill tops, ridges and upper slopes have to be included, cooler northern and eastern aspects are preferable and might carry teak. Other aspects should be planted with other species. Areas where rainfall is very heavy should also be avoided. Again, if teak is to be planted, the drier southern and western aspects are more suitable.

(iii) The soil should be well drained, but moisture retentive, deep, porous, friable sandy or silty clay loams of well developed structure. Lateritic and stiff clayey soil should be avoided. Sites along the banks of streams with well drained alluvial soil, but high enough to escape the flooding of the stream are also preferable.

(iv) It is also important to facilitate effective weed control, to have adequate stocking of small trees and shrubs, particularly bamboo for burning (see Chapter VII). However, if effective weedicides are available this factor may be ignored.

CHAPTER V

FLOWERING, SEEDING, AND GERMINATION

5.1 Flowering

Teak flowering is important in quantity and quality control of timber production as well as seed production.

The species is monoecius and flowers freely every year (Kermode, 1957; Gram and Larsen, 1958; Haig *et al*., 1958). Most tree species have flowering buds either lateral or terminal on side branches and flowering occurs on the main axis only when the tree is fully grown or over-mature (Gram and Larsen, 1958; Boonkird, 1966). Teak however differs from most other tree species in that it flowers early in the life of the tree, with the inflorescence terminal on the main axis (Kermode, 1957; Gram and Larsen, 1958; Haig *et al*., 1958; Boonkird, 1966). This may also be accompanied by panicles on some of the side branches (Gram and Larsen, 1958; Boonkird, 1966) and inflorescences may be formed only on side branches if the top of the main axis is injured (Gram and Larsen, 1958). White (1962) from his observation in Papua New Guinea teak plantations qualified the supposition that the flowering was terminal. He noted the flower as axillary and apparently terminal. All flowering heads on the main axis still showed the presence of an apical bud, and out of 1064 trees that flowered, 2.4 per cent demonstrated vigorous terminal growth which continued past the flowering zone. White felt the apical bud in the supposedly terminal flowering type becomes reduced by the drain imposed due to flower and fruit growth, and death of the bud follows caused by dessication and starvation.

An inflorescence may consist of 5000-8000 buds, though not all of these will develop (Cameron, 1968). For individual inflorescences, the flowering period lasts from two to four weeks (Bryndum and Hedegart, 1969). But there are differences in time of flowering of individual trees and this gives a long flowering period for the species in a particular locality. In India and Burma, teak flowers from June through to September, and from mid-July until November in Northern Thailand (Kermode, 1957; Haig _et al._, 1958; Bryndum and Hedegart, 1964). In Indonesia, however, the time of flowering varies with locality. In the western part of Java, the species flowers from December to February and in the eastern part, one month later (Gärtner, 1956).

Cameron (1966) believed both self- and cross-pollinations occur in teak, with insects and wind the major pollinating agencies. This was qualified by studies carried out in Thailand by Bryndum and Hedegart (1969). These consisted of

(i) isolating and comparing two lots of inflorescences one of which (7-isolation bags) was supplied with insects, and the other (9-isolation bags) was not. Each bag contained one inflorescence

(ii) placing two inflorescences from neighbouring trees together so that the isolation bags contained flowers from both trees. Six bags containing the combined inflorescences were supplied with insects, and the others (5 bags) were not

(iii) selfing and crossing by hand pollination, and

(iv) open pollination.

The seed produced by self-pollination proved very infertile giving only 13 per cent germination compared with 90 per cent for the cross-pollinated materials. The results as shown in Table 14 indicate teak as mainly a cross-pollinated species with insects acting as the main pollination agency. It is also clear controlled pollinations as practised by Bryndum and Hedegart were not very successful.

Table 14. Development of fruit from self- and cross-pollination as given by Bryndum and Hedegart (1969)

Type of pollination		Fruit per inflorescence
(i) Bags with one inflorescence	(a) with insect	5.5
	(b) without insect	1.3
(ii) Bags with two inflorescences	(a) with insect	26.6
	(b) without insect	2.4
(iii) Hand pollination	(a) selfing	1.3
	(b) crossing	5.2
(iv) Open pollination		41.4

The terminal inflorescence on the main axis in teak usually results in die back of the leader and development of either severe forking with two or more competing leaders or at best a bad dog-leg (Gram and Larsen, 1958; Chalmers, 1962; White, 1962; Boonkird, 1966; Larsen, 1966). Subsequent flowering is also frequently terminal on the main axes which resulted from the initial forking. This leads to a multitude of forked stems and a broad crown is soon formed (Gram and Larsen, 1958). Normally only the portion of the stem below the fork yields marketable log. However, there are cases where marketable logs are obtained from large forked stems, especially when the fork is low. Clearly however trees which initially flower relatively late in life are desirable as these will have larger boles than trees with earlier initial flowering.

The presence of variation in the age of first flowering in teak has been recognised by several authors (Gram and Larsen, 1958; White, 1962; Boonkird, 1966; Cameron, 1966; Larsen, 1966). Generally, teak flowers in the fifth or the sixth year (Boonkird, 1966), but it is not uncommon to find teak flowering at two to three years of age (Chalmers, 1962; White, 1962; Boonkird, 1966). There have been differences of opinion as to the cause of initial flowering in the species. Boonkird (1966) felt this feature was mainly determined genetically. Gram and Larsen (1958) considered that as well as a genetic control, delayed flowering could also be due to light deficiency, whereas Kermode (1957) believed early flowering to be due to unfavourable site conditions. This needs further research, for, although the observations of Boonkird (1966), and Gram and Larsen (1958) in Thailand have indicated a genetic control, conditions which might stimulate initial flowering and thus inhibit bole development need to be fully understood.

The frequency of flowering in teak may also affect timber production. Boonkird (1966) from a separate study on nine and ten year old plantations in Thailand demonstrated a decrease in height growth as the frequency of flowering increased (Table 15). Diameter growth did not however seem to be affected.

Table 15. Effect of frequency of flowering on girth and height growth over a four year period as given by Boonkird (1966)

No. of trees	No. of years which flowering occurred	Average girth growth (cm/year)	Average height growth (cm/year)
5	-	3.25	0.87
4	2	3.94	0.84
7	3	3.82	0.62
4	4	3.50	0.60

Thus, besides the usual biological role, flowering has a direct effect on both the quality and quantity of teak timber production. This will present problems for the tree breeder, for it is clearly desirable to select both for late initial flowering individuals and also for trees which do not flower frequently.

5.2 <u>Seed and seed production</u>

The teak "seed" normally referred to in the literature is in fact a fruit and not a seed. The erroneous usage is however widespread. Consequently throughout this thesis, the word "seed" will be used unless it is necessary to emphasize otherwise.

Teak fruit has a thick and leathery exocarp, enclosing a hard stone-like endocarp which usually contains four seed chambers (Bryndum, 1966). Joshi and Kelkar (1971), in a study on teak seed from a dry locality in India found that out of these four loculi, on average, only one contained fully developed seed at maturity, two loculi usually remained under-developed and the fourth contained either rudimentary or seed of medium development. In Thailand, Bryndum (1966), found that in a 10.5 - 11.5 mm diameter class (presumably the normal fruit size in Thailand) fruits, 34 per cent were empty, 44 per cent held one seed, 16 per cent held two seeds, 4 per cent held three seeds, and 2 per cent four seeds. The development of seeds in the fruit in teak is therefore very poor.

Takle and Mujumdar (1957), and Haig et al., (1958) considered teak generally starts producing large quantities of fertile seed at the age of 15-20 years. Experiments in Indonesia also indicated that large quantities of viable seeds can be obtained in stands aged 20 years on good quality sites and 30 years on poorer sites, with germination capacity of the seeds deteriorating as the age of the parent trees approach 100 years.

Seed production is relatively poor as compared to the profuse flowering of the species (Kermode, 1964). Normally, one flowering head which contains 5000-8000 flowering buds, yields only 40-60 seeds (Gärtner, 1956; White and Cameron, 1965). However, a study in Keravat, Papua New Guinea indicated that trees aged 8-14 years with reasonably free crowns would yield approximately six pounds (4,200 seeds) per tree (White and Cameron, 1965). A later report of five older trees in Keravat over a period of three years recorded from age 14 to 16 years gave an average of

14.8 pounds (10,400 seeds) per tree (Cameron, 1968). It appears that the seed yield increases with age within the age limits specified to date. The viability of seed collected was however not mentioned. According to Gärtner (1956), teak trees studied in Papua New Guinea would appear to be still too young to produce viable seed in quantity. However, teak in Papua New Guinea generally grows faster and starts flowering at a younger age (second to fourth year) than in northern Thailand or Central India where the climatic conditions are severe (Cameron, 1968). Thus, there must be the possibility that the species could produce viable seed in quantity at an early age.

In India and Burma, teak seeds start to ripen in November - January, about five months after flowering and are shed till the end of the hot season in April (Haig et al., 1958; Kermode, 1964). In Indonesia, the seed ripens and falls from April - November (Gärtner, 1956) which is also about five months after flowering. Seed collection is normally carried out in March in Burma, and early fallen seeds are never collected as they are usually either not well developed or damaged (Gärtner, 1956; Kermode, 1964). Work done in Indonesia, as summarized by Gärtner also indicated that seed collected in season contains less immature and damaged seeds and has a better germination than seed collected earlier. This is illustrated in Table 16 where the percentage of damaged and immature seeds decreased and the germination per cent increased with time of collection varying from June to September. Seeds collected late in

October appear to decline in quality again. Clearly the best time for seed collection in Indonesia would be during August, September, and October.

Table 16. Details of the variation in the proportion of damaged and immature and viable seed with time of collection as given by Gärtner (1956)

Time of collection	June	July	August	September	October
% damaged or immature seed	58.0	26.0	7.0	4.0	17.0
Germination % seed collected	27.2	34.5	43.3	52.2	50.8

5.3 <u>Germination and dormancy of teak seed</u>

Germination in teak seed is usually very poor (Maung Gale (2), 1958; Kermode, 1964; Bryndum, 1966). Experiments in Burma indicated that germination is much poorer in the natural forests than in open nurseries (Kermode, 1964), and this is illustrated in Table 17.

Table 17. Comparison of germination of teak seed in natural forests and open nurseries in Burma as given by Kermode (1964)

Year	Centre	No. of proven-ances	Highest germination % in natural forests	Highest germination % in open nurseries
1938	Zigon	5	6.0	16.0
	Tharawaddy	5	1.8	38.0
1939	Zigon	11	1.2	59.2
	Tharawaddy	11	0.3	40.4
1940	Zigon	11	-	51.0
	Tharawaddy	11	18.0	42.5

The cause of poor germination is generally due to either a seed coat condition which prevents the entrance of water and oxygen, or conditions within the embryo which prevent germination and make after ripening necessary, or structural immaturity of the embryo (Nikolaeva, 1969; Joshi and Kelkar, 1971). In teak poor germination appears to be due to a combination of all these conditions (Gärtner, 1956; Bryndum, 1966; Joshi and Kelkar, 1971). Joshi and Kelkar carried out a viability test with tetrazolium chloride on a batch of well developed teak seed from a drier part of India. Tetrazolium chloride is colourless in the oxidised form, but when reduced, as by viable embryos, it gives an intense red or orange stain (Flemion and Poole, 1948). The test revealed that 20 per cent of the teak seeds tested gave positive results, 40 per cent produced a feeble reaction (the authors considered these would respond to after ripening) and the remaining 40 per cent did not respond at all, and were considered to be structurally immature which would not respond to any treatment. Thus, the condition within the embryo alone accounted for approximately 80 per cent of the poor germination in teak seed.

Storage of teak seed for one year is generally considered to improve germination (Anon, 1956b). This could be due to the process of after ripening, which takes place either on the tree itself or during storage (Gärtner, 1956). Gärtner believed that the process of after ripening reaches a certain stage while the seeds are still on the tree and seeds harvested during the early part of the season do not reach this stage and thus give poor germination (Table 16). The time of seed collection and the period of seed storage is therefore very important in the germination of teak seed.

The extremely low germination in natural forest (Table 17) could be due to the seed bed being shaded by the natural stand, for germination of teak seed has been found to be poorer under shade than in the open (Bryndum, 1966; Maung Gale (2) and Nyunt Naing, 1967). A light requirement for germination of teak seed was also indicated in one of the author's exploratory experiments, when an attempt was made to germinate 40 pretreated teak seed in a dark room at 30°C. No germination was obtained till the 30th day or sowing, while those sown in a lighted incubator maintained at 36°C started germinating on the 9th day.

Germination of teak seed was also found to vary with origin (Anon, 1956b; Wijesinghe, 1963; Maung Gale (2) and Nyunt Naing, 1967). Seed from moister parts of India were found to germinate more readily than those from drier regions (Anon, 1956b; Wijesinghe, 1963). Similarly, teak from Lower and Central Burma gave 35-59 per cent germination whereas those from Upper Burma gave only 7-20 per cent germination (Kermode, 1957; Maung Gale (2) and Nyunt Naing, 1967). The author has noticed that teak seeds from the moister region are generally bigger in size than those from the drier region, and presumably also have greater vigour in germination. This tends to explain the observation made in India which indicated the superiority in germination of seeds collected from moister areas. However, the superiority in germination of seeds from Central Burma, which is relatively drier than Upper Burma is contradictory to the above. It therefore suggests the involvement of other factors apart from moisture status of the origin of the seeds collected.

The extremely low germination of seed in natural forests suggests methods of management in such forests might have considerable difficulty in producing adequate regeneration. Thereby giving an additional stimulus to plantation forestry.

5.4 Seed pretreatment

From the above discussion, it is clear that teak seed presents a problem in germination. Normally the germination is very sporadic, and even under favourable conditions, it may take three months or more for all seeds capable of germinating to do so (Bryndum, 1966). This results in uneven sized seedlings which are undesirable both for planting and for research purposes. Distribution of seddlings within the beds is also usually erratic, causing management difficulties and wastage of space. Thus, it becomes necessary to find a seed pretreatment method to give better and more even germination.

Soaking in water (i.e. in a running stream water) for a few days or alternate soaking and drying is the most widely used method of pretreatment in the tropics (Letourneux, 1957). The process of alternate soaking and drying probably causes expansion and contraction of the hard seed coat to weaken it, thus facilitating germination. Teak seed will open even when no embryo is present in the seed chamber (Bryndum, 1966). Therefore Bryndum assumed opening of the fruit was achieved mechanically by expansion and contraction of the endocarp at varying vapour pressures. However, if this was so, the alternate soaking and drying method of seed pretreatment would be superior to plain soaking, even though soaking alone may also weaken the seed coat. However, Wijesinghe (1963) in comparing these two methods of teak seed pretreatment in Ceylon demonstrated that continuous soaking in water for three days gave significantly better germination (19 per cent) than alternate soaking and drying for 14 days (13 per cent). In a separate experiment, Wijesinghe found the optimum period for continuous soaking to be two days.

Certainly, weakening of the seed coat is of prime importance to germination. Different methods of pretreatment of teak seeds have also been tried in India and Burma, and they are as listed below (Anon, 1956). All are designed to weaken the seed coat.

(1) Scorching the seed by spreading in a light fire of leaves or grass.

(2) Immersion of seed in hot water for a few hours.

(3) Boiling water treatment, i.e. putting the seed in boiling water and allowing the whole to cool.

(4) Immersion in cold running stream water for a number of days.

(5) Alternate soaking in running stream water and spreading and drying.

(6) Burying the seed near an ant hill, so that the white ants destroy part of the seed coat.

(7) Placing the seed in a paste of cow dung and water.

(8) Exposing the seed to sun and rain by leaving it in the open for a few weeks.

(9) Acid treatment.

Experiments by Bryndum (1966) in Thailand showed the removal of the leathery exocarp by exposure to attack by ants improved germination considerably. Germination of the treated seed was further improved by either soaking in water for 48 hours or subjecting them to the soaking and drying process. Over 90 per cent germination was obtained by subjecting the seed to ant treatment for 33 days and then a rapid soaking in water and sun drying (four times soaking, three times drying in 30-45 minute periods).

The removal of the leathery exocarp probably improves permeability and gaseous exchange, thus improving germination. A machine for removal of the leathery exocarp of teak seed has been constructed by the Thai Danish Teak Improvement Centre in Bankok (Hedegart, 1971). Although it is still in the experimental stage, the results obtained in Thailand and Laos were encouraging (Hedegart, 1971; Wood, personal communication), but the sporadic distribution of seedlings in the nursery still remained a major problem.

The germination of teak can therefore be very poor. Even with the use of various pretreatment procedures, germination can be very variable. The author experienced difficulties in attempting to germinate teak seed. The generally unsatisfactory nature of teak germination suggested an investigation of various pretreatment procedures should be made to determine a satisfactory laboratory technique and possibly provide a guide for field practices. Initially an exploratory experiment on a wide range of seed treatments was carried out. This experiment (detailed below) covered soaking or soaking and drying treatments, chemical, and mechanical treatments.

Two methods (i) seed coat removal and (ii) alternate soaking and drying gave the best performances. Alternate soaking in tap water and drying was chosen as most suitable as mechanical removal of the seed coat caused considerable damage to the embryos and was tedious. Most importantly, however, seeds so treated were killed by fungal infections in the phytotron.

In order to further improve the germination, another experiment involving different periods of alternate soaking and drying treatments followed by germination under two different temperature regimes was carried out.

Seed treated with alternate soaking in running tap water for 24 hours and drying for 24 hours over a period of three weeks followed by germination temperature of 36°/31°C (day/night) gave the best germination. This procedure was therefore used for the later experiment. Details of the experiments on pretreatment procedure follow.

5.5 Experiment on wide range of seed pretreatment

5.5.1 Object

To study the effect of different soaking, chemical and mechanical pretreatment methods on germination of teak seed as an exploratory experiment.

5.5.2 Materials and methods

Teak seed from Papua New Guinea had the following eight treatments applied :

Soaking treatment

(1) Alternate soaking in running tap water and drying: Teak seeds were alternately soaked in running tap water and spread to dry at room temperature for 24 hours each. This process was repeated for 14 days.

(2) Soaking in running water: Teak seeds were submerged in running tap water at room temperature for three days.

Chemical treatment

(3) Alcohol treatment: Teak seeds were soaked in absolute ethyl alcohol for 24 hours, and then transferred immediately into running tap water at room temperature for 48 hours.

(4) Nitric acid treatment: Teak seeds were soaked in two per cent nitric acid solution for 24 hours prior to sowing.

(5) Sulphuric acid treatment: Teak seeds were soaked in concentrated sulphuric acid for (a) one hour (b) two hours (c) three hours respectively. The seeds were then thoroughly washed with water before sowing.

(6) Gibberellic acid treatment: Teak seeds were sown between cotton gauze placed in petri dishes. The cotton gauze was kept moist with 50 mg/1 gibberellic acid throughout the experiment. No watering was done.

(7) Hydrogen peroxide treatment: Teak seeds were sown between cotton gauze placed in petri dishes. The cotton gauze was kept moist with two per cent hydrogen peroxide solution throughout the experiment. No watering was done.

Mechanical treatment

(8) Removal of seed coat: The hard seed coats were cracked with a vice and removed. The naked embryo were sown in tin trays as described below.

Control

(9) Control: No pretreatment was given prior to sowing.

Seeds for six of the eight treatments and a control were sown in 11 cm x 22 cm x 8 cm tin trays containing a mixture of 1:1 perlite and vermiculite. 40 seeds were sown for each treatment, and the trays were placed in a glass window incubator illuminated with a 40-watt bulb. The trays were watered once at 9 a.m. and once at 5 p.m. every day.

5.5.3 Method of assessment

Seed germination is generally assessed as the total germination per cent (Gärtner, 1956; Czabator, 1962; Wijesinghe, 1963; Kermode, 1964; Bryndum, 1966). However, this method of assessing germination can be misleading for total germination varies with the length of time the test is conducted (Czabator, 1962). Interpretation of germination may therefore be incorrect or misleading if only total germination is considered. Czabator (1962) developed a method of germination assessment in which both speed and totality of germination were expressed as a single numerical value. Czabator calculated a germination value wherein

$$GV = PV \times MDG$$

where, GV = germination value

PV = peak value

MDG = mean daily germination

Peak value (a measure of the energy or vigour of the seed lot) is expressed in terms of the highest germination per cent in relation to elapse of time from the start of a test. Thisis determined by successively dividing the cumulative germination per cent by the number of days until a quotient giving the highest value (PV) is obtained. Normally, the quotient becomes progressively less for each day on either side of the peak day.

Sometimes more than one peak may develop during the course of germination. In such a case, it is safer to draw a graph and study the trend of the curve before deciding which peak to use in calculating the peak value. Some may be due to fluctuations which are too small to be considered as a peak and in such cases, it is more reasonable to use the more prominent peak which forms a shoulder in the mean course of germination.

Mean daily germination is the average number of seeds germinating per day of the actual test period to the date of measurement. It is calculated by dividing the total germination per cent on the closing day by the total number of days.

Records of germination were taken daily and germination for each fruit was counted as one, although some fruits produced up to four seedlings.

5.5.4 Results and discussion

Results obtained in the experiment are shown in Table 18.

Table 18. Results of germination of teak seed treated under a wide range seed pretreatment methods

Treatment	Peak value (PV)	Mean daily germination (MDG)	Germination value (GV) PV x MDG
Alternate soaking and drying	0.74	0.55	0.41
Soaking for 3 days	-	-	-
Ethyl alcohol (absolute)	-	-	-
Nitric acid	0.46	0.46	0.21
Sulphuric acid (Conc.)	0.25	0.12	0.03
Gibberellic acid	0.37	0.37	0.14
Hydrogen peroxide	0.56	0.56	0.31
Seed coat removed	2.19	0.65	1.42
Control	0.65	0.65	0.42

The removal of the seed coat proved by far the most successful technique. This treatment had a far higher germination value than any other and a higher peak value, the latter indicating rapid germination. However, overall germination as indicated by MDG figures was no better than control. Of the other treatments, soaking and drying had a similar germination value to the control but actually produced more rapid germination (PV) and lower overall germination (MDG). All other treatments were inferior to the control, mostly by appreciable margins, and two treatments, continued soaking and the alcohol treatment, produced no germination at all.

This suggested chemical treatments were of little value and mechanical removal of the seed coat was the best method. However, on the four occasions this method was employed in the phytotron, under the prevailing humid conditions all germinating seeds were killed by fungal growth. Considerable care may therefore be necessary in germinating seeds with the seed coat completely removed, especially under humid conditions. Furthermore, the process is extremely tedious as the fruit coat had to be broken open by hand to avoid damage to the embryos as far as possible. Despite precautions, some damage occurred.

The soaking and drying technique proved much more reliable although slower. It was also a much simpler technique and was therefore applied for all experiments in the controlled environments.

5.6 Experiment on alternately soaking and drying pretreatment of teak seed

5.6.1 Object

To study the effects of different periods of soaking and drying pretreatment, and temperature on the germination of teak seeds.

5.6.2 Materials and methods

This experiment was conducted in the open glasshouses at the C.S.I.R.O. phytotron (see Chapter XI). A batch of teak seeds of Papua New Guinea origin was thoroughly mixed and randomly divided into four seed lots. 200 seeds were randomly taken from each seed lot. One lot was kept as control with no pretreatment given, whilst the remaining three seed lots were alternately soaked in running tap water at room temperature for 24 hours, and spread out in tin trays and dried in 30°/25°C open glasshouse for 24 hours. The process was repeated for one week for the first seed lot, two weeks for the second seed lot, and three weeks for the third seed lot. The process was started at one week intervals so that all treatments were ready for sowing on the same day.

The seeds were sown in 15 cm top diameter plastic pots containing a mixture of 3:2 perlite and vermiculite, and were covered with approximately 0.5 cm deep of the same mixture. Each pot contained 20 seeds and a replicate of 5 x 20 seeds was used for each treatment. One set of the sown seeds (i.e. containing control, and those pretreated for 1-week, 2-weeks, 3-weeks), were put in 30°/25°C open glasshouse, and another set was put in 36°/31°C open glasshouse. All the pots in the two glasshouses were placed in troughs containing water approximately 2.5 cm deep. The level of water in the troughs was maintained throughout the experiment. The pots were also watered once at 8.30 a.m. and once at 3.30 p.m. daily.

Table 19. Germination value (Recorded data)

Pretreatment	30/25°C	36/31°C	Mean
Control	0.008	0.017	0.013
1-week	0.075	0.091	0.083
2-week	0.274	0.227	0.251
3-week	0.365	0.592	0.479
Mean	0.181	0.232	

L.S.D. = 0.180

Table 20. Analysis of variance for recorded data

Source of variation	d.f.	Sum of squares	Mean squares	F
Temperature	1	0.026153	0.026153	0.71
Pretreatment	3	1.288208	0.429403	11.67 *
Interaction	3	0.108581	0.036194	0.98
Residual	32	1.177215	0.036788	

Table 21. Germination value (substituted with missing plot value for anomalous record)

Pretreatment	30°/25°C	36°/31°C	Mean
Control	0.008	0.017	0.013
1-week	0.075	0.091	0.083
2-week	0.143	0.227	0.185
3-week	0.365	0.592	0.479
Mean	0.148	0.232	

L.S.D. = 0.143

Table 22. Analysis of variance for data substituted with missing plot value

Source of variation	d.f.	Sum of squares	Mean squares	F
Temperature	1	0.070283	0.070283	2.86
Pretreatment	3	1.261982	0.420661	17.13 **
Interaction	3	0.076516	0.025505	1.04
Residual	31	0.761097	0.024552	

5.6.3 Results and discussion

The results of the experiment were calculated as described above for the previous experiment under sub-section 5.4.3 and they are as shown in Tables 19 and 21 and Figure 9. The germination improved with the increase in the period of soaking and drying within the limit studied. The effect of germinating temperature however was not significant. However, examination of the data for the two week treatment at 30°/25°C suggested one of the five values to be anomalous as this was approximately four times as big as the next largest. Accordingly, a missing plot substitution (Freese, 1967) was utilized to replace the value, and the results were calculated for both the entire original data and also for the data including the missing plot value. Both results are detailed in Tables 19 and 21 and Figure 9.

Germination commenced 11-14 days after setting out in all batches except the batch that was pretreated for one week only and germinated under 30°/25°C and also the control batches. The batch pretreated for one week and germinated

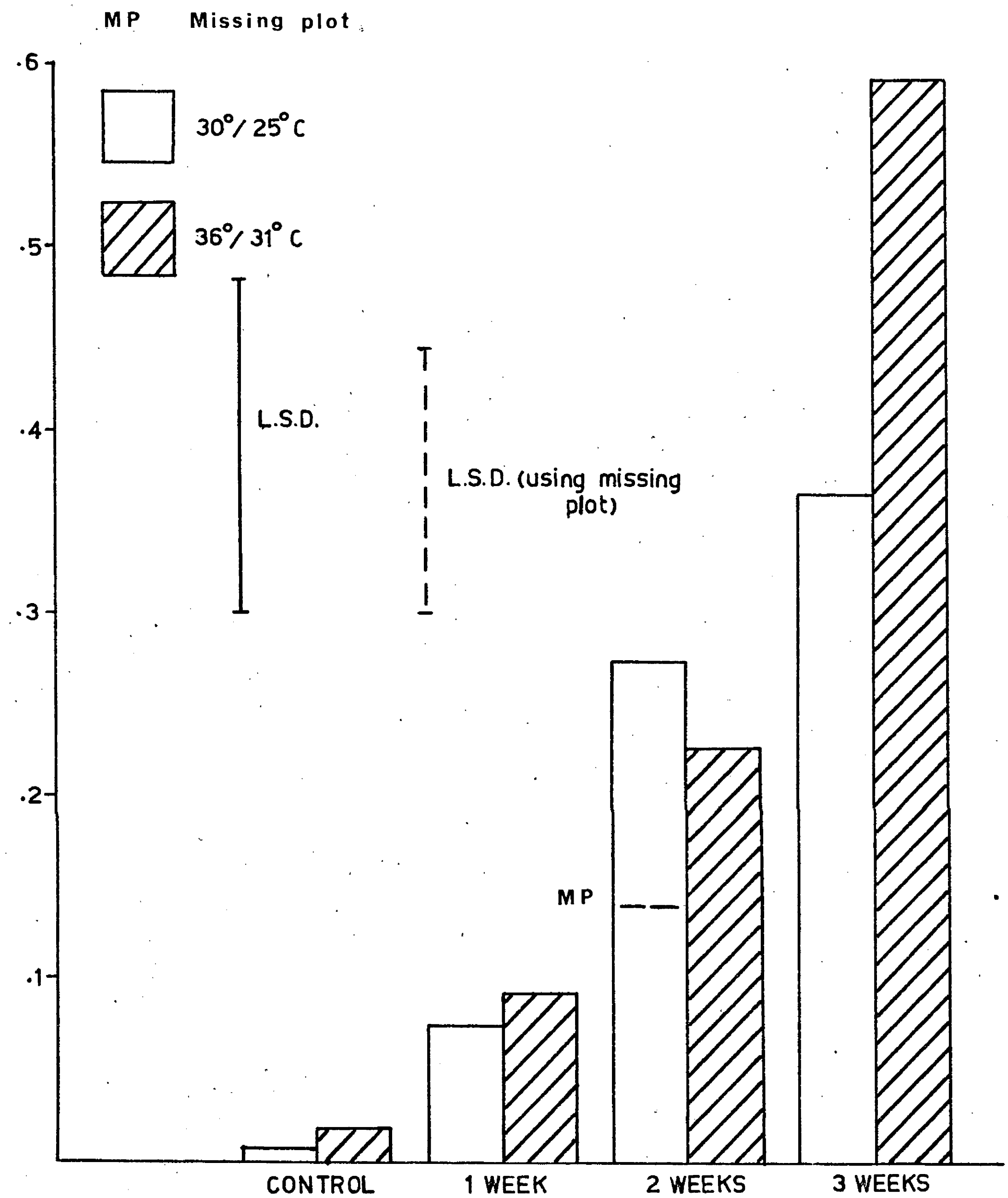


Figure 9 Histogram showing the effects of different periods of alternate soaking and drying pretreatment and temperature on germination value of teak seed.

under 30°/25°C started germinating on the 21st day and the control batches germinated under 36°/31°C and 30°/25°C on the 31st and 32nd day respectively. There were indications that germination was slightly more rapid at the higher temperature, and germination clearly commenced earlier at longer periods of alternate soaking and drying pretreatment within the limits studied.

The analysis of variance showed the results due to the various pretreatments differed significantly at the one per cent level (Tables 20 and 22). The batch pretreated for three weeks was significantly the best (Tables 19 and 21). Seeds pretreated for two weeks also gave a significantly higher germination value than the control, but thedifference between the batch pretreated for one week and control was not significant. Thus, the germination value increased with the increase in alternate soaking and drying pretreatment period from no treatment to three weeks.

The effect of germinating temperature on the germination value was not significant, even when the missing plot substitution was made. However, there are indications that germination value tends to be higher at 36°/31°C than at 30°/25°C (Tables 19 and 21). Possibly the effect of temperature was masked due to the erratic nature of teak germination. Larger numbers of samples might give some positive results for temperature effects.

Since germination of teak seed was best after being pretreated by alternate soaking and drying for three weeks, this technique with 36°/31°C germinating temperature was adopted for the main experiment. However, three weeks cannot be considered as the optimum period of alternate soaking and drying pretreatment, as the effect of further increasing the pretreatment period was not determined. Further study is needed to determine the optimum period of pretreatment method and temperature effects. If high temperatures do improve teak seed germination, a method of heating nursery beds will prove useful.

CHAPTER VI

NURSERY TECHNIQUE

6.1 Teak nursery procedure

Teak seedlings are very hardy and fairly easy to raise in nurseries (Haig, *et al.*, 1958; Kermode, 1964). They grow quickly and the usual procedure is to sow seeds at the very beginning of the rainy season (April in Burma). The resulting seedlings will then be of the order of approximately 0.6 metres high at planting time 13 months later. For planting, the seedlings are cut back to 'stumps', where part of the stems and roots are cut off and the only section retained is about 2.5 cm of the lower stem and approximately 15 cm of root. When planted, these stumps sprout and quickly develop as established trees.

Teak seedlings may be raised in either temporary or permanent nurseries. Generally, temporary nurseries are used to regenerate small scattered areas whilst permanent nurseries are used for concentrated regeneration of large areas or to supplement temporary nurseries. Both have their merits and demerits. However, there are many features common to the management of both nursery types.

6.2 Type of nursery

Temporary nurseries are established near planting sites, and are used for one to three years. Permanent nurseries on the other hand may be established to serve over a longer period of time and may supply seedlings to several different planting sites.

Kermode (1964), believed there was no need for an elaborate nursery for raising teak in Burma. He felt a temporary nursery should be used for one season only. It should be established in the current year's plantation area, and the nursery stock used for planting the adjoining area the following year. Similarly in Trinidad, teak temporary nurseries were generally used for only one year, but where soil fertility was high, the site was used for two years (Lamb, 1957). In Papua New Guinea and Tanzania, it is the usual practice to use teak temporary nursery sites for two or three years (White and Cameron, 1965; Wood, 1967). Thus, temporary nurseries frequently have a life of more than one year.

Temporary nurseries are most practical where scattered small areas are to be planted, especially if there are associated transportation difficulties. They suffer however in that close supervision is not usually possible and losses may occur due to factors difficult to control under such circumstances. For example, in Burma, temporary nurseries are normally established close to streams to facilitate watering. This practice however makes the nursery susceptible to flood damage. Another frequent cause of losses in these isolated nurseries is cattle damage. Both these factors have led to substantial losses in some Burmese temporary nurseries. To obviate the problem, current Burmese practice is to have temporary nurseries at all regeneration centres and any shortages are made up from four permanent nurseries situated at strategic localities throughout the country. Permanent nurseries are presently situated at

Hmawbi (near Rangoon), Toungoo, Taunggyi, and Katha (see Figure 1 for locations).

Permanent nurseries have the advantage of allowing work to be concentrated, thus facilitating mechanization and allowing close supervision by skilled staff. In consequence, permanent nurseries usually produce both better quality seedlings and a greater quantity of seedlings than do temporary nurseries (Iyamabo, 1957). Permanent nurseries would thus be particularly useful where regeneration of a large area is to be carried out quickly.

However, there can be major difficulties in the maintenance of soil fertility in permanent nurseries, especially in tropical areas (Venkataramany, 1956; Wood, 1967). In Tanzania, a teak permanent nursery used continuously for seven years lost fertility despite regular fertilizer applications. The result was both a reduced outturn of stumps and the production of unhealthy stumps (Wood, 1967). Venkataramany (1956) summarized the results of research on artificial regeneration of teak in Madras State (India) from 1926 to 1956. He similarly reportedthat even with regular application of manure, the repeated use of nursery beds year after year caused considerably falling off in production of teak stumps, both in size and number. Unfortunately, neither Wood nor Venkataramany specified the nature and quantity of fertilizer and manure applied. However, it would be unwise in the light of this experience to expect permanent nurseries to have a useful life of more than seven years.

There are, therefore, problems with both nursery types. Temporary nurseries frequently fail to satisfy supply requirements. On the other hand permanent nurseries are expensive to install, may only have a limited life and are unsuitable if transport is difficult. Permanent nurseries do, however, provide better quality stock and usually meet supply requirements.

The need to balance these various conditions means nursery practice varies appreciably from place to place. In India, for example, personal communication and examination by the author in the field have revealed a very wide diversity in nursery practice. Indeed the variation is so great that entirely different procedures may be followed in neighbouring forest divisions. However, in the future as mechanization and transportation procedures improve, and large scale plantation becomes more common, it is likely permanent nurseries will be more widely used than at present.

6.3 Site selection

Site selection is the most important phase in nursery establishment in the tropics. Selection of unsuitable sites can lead to failure or make the cost of running the nursery uneconomical. Generally, topography, drainage, water availability, physical and chemical properties of the soil, and accessibility should be considered (Taylor, 1962; White and Cameron, 1965).

Although site selection is clearly more important for permanent than for temporary nurseries, it is nevertheless a major consideration in all nursery establishment. White and Cameron (1965) outlined the following criteria for the site of a temporary teak nursery in New Guinea as :

(a) A level or gently sloping site of sufficient area to allow for a cleared surround at least one chain wide and located in rainforest country.

(b) Local depressions, where water may collect, are to be avoided.

(c) Areas of dense herbaceous or grass cover are to be avoided as weed problems will be severe.

(d) The nursery should be sited on a light sandy loam soil which is deep and has good internal drainage.

(e) The area must be, or capable of being readily made accessible to vehicles.

(f) A site to serve two to three years, and adjacent to the planting area for that period is preferable.

The specified criteria for site selection for temporary teak nurseries in Burma are principally the same as in Papua New Guinea, although not identical.

The major difference in the site selection of a permanent nursery as opposed to a temporary nursery is the need to have the nursery in close proximity to headquarters, thus facilitating intensive technical supervision and maintenance. Iyamabo (1967) has summarized the requirements of a temporary tropical nursery noting that although it is desirable to have the nursery close to planting areas, expert supervision, skilled labour, and facilities for equipment maintenance are of greater importance. However, where the nursery is not located in close proximity to the planting site, differences between the ecology of the nursery and the planting site should be such so as not to adversely affect the plants' establishment (Métro, 1967). The physical condition of the soil at the nursery site is very important. In general, light sandy loams are preferable (White and Cameron, 1965; Stevens, 1971). These authors felt soil condition to be much more important than the nutrient status, for this could easily be improved by fertilizers.

6.4 Nursery bed preparation

The general practice in preparing a teak nursery bed is to clear fell the area selected, uproot all bamboo clumps and large stumps, and then to burn the area. Where cultivation is to be carried out manually, the bed position is marked immediately after the area has been cleared. A width of approximately one metre is usually favoured as facilitating manual weeding. Beds should run at right angles to the slope, and the length of the beds depends upon the topography and other factors (Taylor, 1962; White and Cameron, 1965).

The soil in beds is dug to about 20 cm depth. The beds are usually raised to 20-23 cm above the surrounding soil. The bed sides are supported with split bamboos or poles and to avoid water collecting on top, the surface of the beds is either flat or convex.

In mechanized nurseries, the whole area is first ploughed to a depth of 20 cm (LARP, 1972). In New Guinea, the soil is cultivated twice to get a good soil turnover and clod breakdown (White and Cameron, 1965). After preparation, the beds are left to settle naturally before sowing commences.

The type of bed and bed size and orientation is otherwise very similar to non-mechanized nurseries.

6.5 Maintenance of fertility

As noted above, maintenance of soil fertility is a most important aspect of teak nurseries. This is normally effected by application of fertilizer or by using beds in rotation with a fallow period (Allan, 1967; Chandler, 1967; Procter, 1967; Lamb, 1969).

In a temporary nursery used for more than a year or where the soil fertility is low, the fertility of the soil can be maintained or improved by application of fertilizer or manure. However, where the nursery is to be used for only one year, and the soil fertility is high, then application of fertilizer can be very light or perhaps not necessary at all. In Burma, cow-dung manure is used if required to improve soil fertility in teak temporary nurseries.

Maintenance of soil fertility is particularly important in permanent nurseries where there is a considerable drain on soil nutrients due to exposure and repeated use of site (White and Cameron; Iyamabo, 1967).

The most commonly used fertilizer in teak nurseries is a mixture of nitrogen, phosphorus, and potassium compounds (NPK) (White and Cameron, 1965; Bhatnagar, et al., 1969; Henderson, 1970). White and Cameron (1965) recommended a weight : weight ratio of 17:11:20, or 21:14:14 for these elements with the latter preferable. They considered higher phosphate content would promote greater root development. Aldhous (1967) recommended the use of 'slow release' fertilizers such as magnesium ammonium phosphate, potassism metaphosphate, and isobutylidene diurea, which are composed of less soluble materials than those commonly used, and will not therefore be so readily leached when exposed.

Experiments to demonstrate the results of applying fertilizers to nurseries were carried out in India by Bhatnagar, et al., (1969). The treatment involved different levels of nitrogen, phosphorus, and potassium and indicated that teak seedlings respond very well both in total height growth and dry weight to NPK mixture especially with nitrogen and potassium at high levels. Growth however was not increased with an increase in the proportion of phosphorus; no mention was made of root development. Thus whilst White and Cameron recommended an application level of 450 kg/ha in nursery beds using NPK in a 21:14:14 ratio, Bhatnagar et al. concluded that for good growth of teak seedlings, desirable application levels were 680 mg/plant of both nitrogen and potassium and 450 mg/plant of phosphorus. It is conceivable that these different recommendations simply reflect the differing environment of India and Papua New Guinea. What is clear however is the value of a general fertilizer application in nurseries and the possible need to determine the optimum proportion of the major constituents for local conditions.

Fallowing and organic manures are also used to maintain nursery fertility. In Burma, the permanent nurseries are divided into blocks and these are used in rotation with one or two blocks lying fallow each year. Cow-dung manure is also applied to improve fertility. Under this treatment, the nursery at Hmawbi has been used for over ten years without any evident loss of fertility (personal discussion with Assistant Silviculturist, Burma).

Partially crushed lime was applied to nursery beds in Laos as well as NPK at the rate of 100-200 gm/m^2 of bed (Henderson, 1970a). Hedegart (1971) from his experience in Thailand also considered teak seedlings may react positively to calcium combined with NPK.

6.6 Seed sowing

Seed sowing in Burmese nurseries usually commences at the beginning of the rains (April). The seeds are either broadcast or sown in lines spaced 15 cm apart. After sowing it is preferable to roll the beds lightly to press the seed slightly into the bed before covering up.

As a general rule, the sowing depth for any species should approximately equal the diameter of the seed (Taylor, 1962; Letourneux, 1957). However, in the tropics where the rainfall is heavy, Letourneux suggested the depth of soil cover be from one and a half times to twice the diameter of the smallest seed. Generally, approximately 1.0 cm soil cover is used in most teak nurseries (Gärtner, 1956; Leloup, 1957; White and Cameron, 1965; Maung Gale (2) and Nyunt Naing, (1967).

Sowing density is dependent upon the germination percentage of the seed lot used. Generally, the weight of the seed to be sown per square metre is calculated according to the number of seeds per kilogram, the usual rate of germination for the species and site, and the spacing envisaged (Letourneux, 1957).

White and Cameron (1965) suggested sowing rates for Papua New Guinea should be such as to produce 54-65 seedlings per square metre, and they formulated the figures in Table 23 as a guide to sowing rates based upon seed viability and weight.

The rate of sowing in Burma is 190 seeds per square metre aiming at a density of 43-86 seedlings in that area (Maung Gale (2) and Nyunt Naing, 1967). This approximates to the 35 per cent germination class of White and Cameron (Table 23). The density of seedlings prescribed by White and Cameron (185/sq m) thus agrees closely with the Burmese prescription.

Table 23. A guide for determining sowing rate of teak in Papua New Guinea [from White and Cameron (1965)] based on unit area (sq metre).

Seed/Kg	1544	1654	1764	1874	No. of seed sown
Germination %	Weight (g)	Weight (g)	Weight (g)	Weight (g)	
50	84	76	76	69	129
40	107	99	91	84	161
35	122	114	107	99	185
30	137	130	122	114	215
25	168	153	145	137	258

Despite these attempts to prescribe sowing rates the extreme variability of seed germination remains a major problem in teak nurseries. Almost invariably a teak nursery will exhibit considerable stocking variations (section 5.3).

Therefore, development of reliable and even seed germination is a much more important factor than sowing rate.

6.7 Weed and disease

6.7.1 Weed

Weed is a major problem in nursery work, for weed growth inhibits the growth and development of the seedling stock. It is a basic principle of nursery management that nurseries should be kept as free as possible from weed growth. In tropical countries weed growth can be very fast necessitating regular and intensive weeding. Care during nursery establishment eases the later problem, for a good initial burning after felling and uprooting is believed to severely restrict weed growth. Once the nursery is established, the usual practice in most tropical countries is to weed manually, but weedicides are also being tried (Iyamabo, 1967)

The basic principles of weedicide application have been developed in temperate nurseries. Weedicides may be applied either before or after seedling emergence. For example, kerosene can be sprayed before the seedlings emerge from the soil (Aldhous, 1967; Brown and Hall, 1968). It should be sprayed while the weeds are small and hot days are known to give the best kill (Brown and Hall, 1968). Weedicides used successfully both as pre- and post-emergent sprays in *Pinus radiata* nurseries include propazine at 1.1 kilogram of active ingredient per hectare and artrazine at 2.2 kilograms of active ingredient per hectare (Brown and Hall, 1968). Brown and Hall however considered trials under different conditions should be conducted before any weedicide is prescribed for use, as the effect varies with the species, and with variations in air temperature and humidity, soil moisture and texture, and seedling health. This is especially important for the post-emergent weedicides as the seedlings can be greatly affected.

The author feels there is a strong probability that weedicides can be successfully applied in teak nurseries. For example, in Papua New Guinea, weeds were controlled by spraying with white spirit (one litre to 33 sq m) a few days before sowing (White and Cameron, 1965). More extensive use should be considered.

6.7.2 Disease

No disease of importance has been found in teak nurseries in Burma, Trinidad or Papua New Guinea (Kermode, 1964; White and Cameron, 1965; Pawsey, 1970). This is possibly due to the widespread use of temporary nurseries in these countries, for when sites are used for only a short period a build up of pathogens is unlikely.

In Burma, bacterial wilt of teak seedlings caused by *Pseudomonas* spp. was reported to exist in the Hmawbi permanent nursery (Doo, 1967, 1968). This disease, however, was not widespread, and Doo considered it could be prevented by improving soil fertility.

The only serious teak nursery disease was caused by *Helicobasidium compactum* Boediju in Tanzania (Wood, 1967). This disease causes root rot, and can be recognised by a purple velvety cushion of fungal tissue at the base of the stem. Losses were heavy at low fertility sites that had been used for seven years. The condition however was reported to have improved drastically when the nursery was moved to a new site.

Damping off caused by Phytophthora spp. has also been recorded in Papua New Guinea in areas where the soil was too moist. This was controlled by spraying with a solution of 85.1 gm of copper oxychloride to 18.1 litres of water, or by allowing the soil to partially dry out (White and Cameron, 1965).

It appears that most of the diseases in teak nurseries develop due to either low fertility or to too moist a soil condition. Thus, if these two conditions are controlled, disease in teak nurseries can be largely prevented. One simple way to avoid problems is to change the nursery site frequently, and temporary nurseries can be expected to be healthier than permanent nurseries.

6.8 Lifting and stump preparation

Teak seedlings (normally one year old) are lifted for planting at the beginning of the rains in May. The stumps for planting are prepared by cutting off and discarding the stem at about 2.5 cm above the collar. The tap roots are cut approximately 10-20 cm below the collar, using a sharp knife to get a clean cut.

Stumps with one to two centimetres diameter at the collar are considered the best size (Anon, 1956b; Venkataramany, 1956; Anon, 1963; Kermode, 1964). Experiments in the Hoshangabad division, India, showed as stump size increased from the 0.8-1.0 cm class to the 1.8-2.0 cm class,

Table 24. Effect of stump size on development and survival in the field in Tanganyika as was given by Anon (1963)

Treatment	Stump size in cm	Survival %	% with two or more leaders	Mean height in cm	% sprouted after	
					2 weeks	4 weeks
A	1.9-2.5	99	32	65	63	99
B	1.3-1.9	98	22	56	63	96
C	0.6-1.3	93	15	48	36	95
D	less than 0.6	87	16	37	20	94

there was an increase in survival percentage (76 per cent to 91 per cent) of outplanted stumps and also in the mean heights (74 cm to 128 cm) after 18 months (Anon, 1945). This work was supported by another experiment in Rondo, Tanganyika (Anon, 1963). This demonstrated that an increase in stump diameter up to 2.5 cm at the root collar gave progressively more rapid sprouting, higher survival, and better first year height growth. However, the proportion of multiple leaders, an undesirable feature, also increased with stump size (Table 24). This report considered a stump size of 1.3-1.9 cm to be the best as it gave the best combination of the high desirable features and an acceptable level of trees with multiple leaders.

6.9 Storage and transport of stumps

Storage and transport of teak stumps can be particularly important when the supply is from a centralized permanent nursery. Present indications are that storage and transportation over a period of two weeks do not affect survival of teak stumps when planted.

Venkataramany (1956) claimed teak stums could be safely stored for two to three weeks. Experiments by Maung Gale (2) and Soe Tint (1969) in Burma supported this, but indicated a marked decline in viability in stumps stored four weeks or more. Maung Gale (2) and Soe Tint found that teak stumps put in a gunny bag in the shade can stand storage for 14 days with no watering, without affecting survival percentage significantly. However, stumps stored for 21 days tended to have a lower viability (71 per cent) than those stored for 14 days (82 per cent), and the survival percentage of those stored for 31 days (55 per cent) was significantly poorer. Similarly, in Thailand, stumps stored for 36 days gave very poor survival figures (14 per cent) (Hedegart, 1971).

An experiment in India demonstrated the successful transportation of teak stumps by rail and road for periods up to two weeks over distances up to 1600 kilometres (Venkataramany, 1956). Clearly, therefore, teak stumps can safely be transported for periods of two weeks without deterioration in survival following outplanting.

6.10 Discussion

The major problem in teak nursery establishment appears to be the type of nursery to be used. In a temporary nursery the quantity and quality of seedlings is not reliable, whilst establishment of a permanent nursery poses major problems in the maintenance of soil fertility. Temporary nurseries backed up by a few permanent nurseries, as is the practice in Burma, would be most suitable if scattered small areas are to be regenerated. However, if concentrated regeneration of a large area is anticipated, then the establishment of a large nursery may be essential. In this case, most careful consideration will need to be given to the rotational use of the nursery area and the application of suitable fertilizers. An alternative method could be the establishment of a semi-permanent nursery which could be easily moved to another area every six to seven years. The economics of this procedure may be doubtful.

Considerable research into stimulation of seed germination is needed. The experiments detailed in sections 5.5 and 5.6 and the generally sporadic germination recorded for all sowings indicate the magnitude of this problem. Stocking variability in teak nurseries will therefore remain a major problem until uniformity of germination is improved. Once this is done, some variation of sowing rates in order to vary quality and quantity of seedlings can be considered.

The knowledge of the use of weedicides and fungicides in teak nurseries is still very scanty and more research is needed. However, it appears that so long as the soil is not too moist, and the fertility satisfactory, teak nurseries can be free from serious disease.

There is clearly no problem so far as storage and transportation of the stumps are concerned provided the period between lifting and planting does not exceed 14 days.

CHAPTER VII

FIELD ESTABLISHMENT TECHNIQUE

7.1 Field Establishment

The taungya method has been commonly used for the establishment of teak plantations in Burma and most tropical countries (Brooks, 1941; Krishnaswamy, 1951; Haig, *et al.*, 1958; Kermode, 1964). It is a cheap and convenient method of establishment, benefiting both forestry and agriculture with young forest tree seedlings and agricultural crops growing in a mixture. The method is particularly useful in countries with high population pressure. The taungya method however, might not be successful for large scale plantation establishment, or in countries where the demand for land is low. In this case, mechanization of the whole operation would be desirable.

7.2 Taungya method as practised in Burma

The taungya method is a combination of forestry and agriculture. The area selected for taungya plantation is divided and allotted to the cultivators (known locally as 'ya' cutters) for felling. In January or February the 'ya' cutters clear-fell the area allotted which has usually already been heavily cut over, and leave the debris to dry for about two and a half months. All operations subsequent to fellings are supervised by the forestry department. Broadcast burning is carried out before the first light shower in April. Any unburnt debris is collected, piled up and burnt again, and this is known as 'kyunkwe' in Burma.

Staking by bamboo stakes at 1.8 m x 1.8 m is done after the area has been properly burnt, and teak stumps are planted at each stake by the 'ya' cutters. After planting the stumps, the 'ya' cutters are allowed to plant their agricultural crop between the stakes and they tend and weed the teak seedlings whilst tending and weeding their agricultural crop. A typical working schedule in Burma, as given by Kermode (1964) is shown below.

(1)	Area allotment to the 'ya' cutters	15th December
(2)	'Ya' cutting and fire protection	27th Dec.-25th Feb.
(3)	Burning	3rd April
(4)	Kyunkwe	6th April
(5)	Staking	12th April
(6)	Stump planting	15th May
(7)	3-weedings	1st and 2nd Year
(8)	2-weedings	3rd Year
(9)	1-weeding	4th Year

Weeding in the 2nd, 3rd and 4th years is carried out by the forest department with hired labourers.

A survival count is made in the first December after planting, and the 'ya' cutters are given a bonus for each plant surviving according to the rates given in Table 25. No bonus is given to the 'ya' cutter if the survival percentage in his plot is less than 50 per cent and the bonus is thus an incentive to the 'ya' cutters to tend and look after the plants properly.

Table 25. Current bonus rates as prescribed by the forest department in Burma.

Survival %	Rates/plant	Earnings/hectare
	(Kyats)	(Kyats)
50-59	0.04	65.78
60-69	0.05	97.16
70-79	0.06	134.55
80-89	0.08	203.32
90-99	0.09	255.66
100	0.10	299.00

The taungya system is well proven economically. Even after giving the bonus, there is a saving of Ks. 130.97 per hectare or 20 per cent, when the plantation establishment is effected by the taungya method rather than by the use of hired labourers (Table 26). This method of establishment had proved better economically in India and Congo. During the study tour in India in 1962, the author has noted that in Kerala State where land is very valuable, areas had to be allotted to the 'ya' cutters by means of auction, and the forest department, instead of incurring expenditure, earned revenue in establishing teak plantations. Similarly in Congo where _Terminalia superba_ was raised in mixture with bananas under this system, the government made a profit in establishing the plantation after collecting land rent from the 'ya' cutters for five years (Dawkins, 1955).

However, it is becoming increasingly difficult to recruit 'ya' cutters in Burma as they are more interested in other much better paying and less responsible work. Areas selected for regeneration have frequently to be regenerated partly by the taungya method and partly by hired labourers. The need for hired labour is likely to be increasingly important in the future, but such labour is now difficult to recruit in the greater part of the country. Thus, where topographical features permit, mechanization of the whole operation may be preferable. However, in order to utilize a mechanical unit effectively and economically, regeneration work will have to be concentrated into large units.

Table 26. Comparison of cost of establishment (per hectare) by the Departmental and Taungya method.
(Office of the Director of Forests, Burma)

Work	Departmental (Kyats)	Taungya (Kyats)	
1. Fire protection and 'ya' cutting	148.27	--	
2. Kyunkwe	74.13	--	
3. Bamboo stake	49.42	49.42	
4. Staking	24.71	--	
5. Seedling cost	37.07	37.07	
6. Planting charges	19.77	202.63	(1)
7. 3-weedings	66.72	--	
8. Fire protection	19.77	19.77	
9. Temporary building	14.83	14.83	
Total for the 1st year	454.69	323.72	
10. Weeding and fire protection - 2nd year	86.49	86.49	
11. Weeding and fire protection - 3rd year	64.25	64.25	
12. Weeding and fire protection - 4th year	42.01	42.01	
13. Fire protection - 5th year	19.77	19.77	
Total cost of establishment	667.21	536.24	

(1) Bonus to 'ya' cutters calculated at 85 per cent survival.

Kyat 1 = $(A) 0.15

7.3 Site preparation for large scale plantation establishment

The author has been unable to find a description of the establishment procedure for a large scale teak plantation. However, site preparation procedures for most species have similar procedures but do vary little, and thus a general review of large scale site preparation is presented.

For large scale site preparation, mechanical clearing is the most efficient, so long as the topography is suitable (Stuart-Smith, 1967). The methods used will depend upon the size of vegetation to be cleared. Normally, chain saw is used on big trees (over 76 cm diameter) (Brown and Hall, 1968). However, most of the areas to be cleared for teak plantations in Burma are heavily extracted areas, and very seldom contain large trees.

The most widely applied mechanical method of clearing is to run two heavy tractors into the area with a chain or cable between them (Allan, 1967; Stuart-Smith, 1967; Brown and Hall, 1968). The tractors used should be powerful enough for the job, as costs increase greatly if the tractors do not have sufficient power (Brown and Hall, 1968). In Zambia, three standard caterpillar D7 tractors were used as the land clearing unit. Two of these pulled an anchor chain 9 - 15 metres apart, while the third one was used to assist in pushing down big trees (Allan, 1967).

The fallen trees are either pushed into heaps or lines (windrowed) to aid burning. Windrowing also facilitates mechanical tending, thinning and extraction, as it allows paths for machines or vehicles to be driven through. However, on the other hand, if the fallen trees are burnt broadcast, the top soil will be less disturbed, and the nutrient contained in the fallen vegetation would be better distributed (Brown and Hall, 1968). Thus, if the site selected consisted only of small pole size regrowth which can easily be burnt and leave the area clear, broadcast burning is preferable.

7.4 Planting

Tree seedlings can be planted either by hand or by machine. Teak is normally planted by hand. Planting of teak stumps can be very simple and inexpensive. Digging of planting holes is not needed. Normally a hole is made with a dibble of size slightly bigger than the biggest stump, and the stump is inserted into the hole with 2.5 cm of the stem portion above ground level. The soil around the hole is then pushed towards the stump with the dibble so that there is no air space between the root and the soil. This is very important because space between the root of the stump and the soil collects water and consequently leads to root rot.

Information on mechanical planting of teak is so far not available. However, planting machines have been used successfully in planting other bare rooted tree seedlings (Stuart-Smith, 1967). In Victoria (Traralgon), Australia, planting machines are used by A.P.M. for planting *Pinus radiata* D.Don. (field studies and personal communication with A.P.M. forest officer of the district). The machine was capable of planting at the rate of five miles per hour and at the cost of $30 per hectare at 2.1m x 2.1m spacing. Planting machines, if properly adjusted can give better survival as there is less root distortion, and faster rate of planting (10,000-12,000 plants per machine per day) than hand planting (Stuart-Smith, 1967). Stuart-Smith considered that machine planting can be economical only if used over large areas and moreover, they are limited by topography and vegetation.

From work point of view, the use of machines for planting teak stumps could be most suitable, as there is neither leaf nor lateral root on the stump. This will facilitate easier and more regular flow in the machine and therefore less liable to damage to the planting stock. Moreover, the operation of staking also will be eliminated as spacing can be set on the machine.

However, machine planting can be expensive as compared to hand planting, especially in Burma where labour is cheap. Hand planting together with the cost of staking in Burma costs $6.70 per hectare (personal communication, Office of the Director of Forests) whereas, machine planting in Australia costs $30 per hectare. Although direct comparison is not valid due to the differences in standard of living and labour cost, the difference in the cost of machine planting should not be very great as only one person is involved in operating the machine. Thus the comparison of the cost of hand planting in Burma and machine planting in

Australia should give a good indication of the difference in planting cost between the two methods. However, machine planting could be the best way of solving the labour problem if acquirement of labourers should become limited in large scale planting programmes.

7.5 Weeding

Weeding is done either manually or by mechanical or chemical means. In the tropics, weeding is generally carried out manually. However, recently, mechanical weeding has been widely used in Africa (Groulez, 1967; Allan, 1967; Endean, 1967).

Mechanized weeding is effected either by mechanical slashing or mechanical cultivation. At the A.P.M. forests in Victoria, Australia, rotary slashers were used between the rows. This method of weeding requires very accurate spacing, and should be done early before the weeds grow too large to avoid excessive damage to the equipment. Mechanical cultivation is however more effective than slashing as the weeds were usually uprooted. Normally, mechanical cultivation is carried out with medium or light tractor with a disc harrow designed for use between the rows.

The present trend is to use the less expensive method of weeding by using weedicide or arboricide. To the author's knowledge, such chemical weed control in teak plantations is still unknown except for one trial of a 2,4-D and 2,4,5-T mixture in the clonal teak orchard in Trinidad (Murray, 1967). The procedure and mixture used were based on those successfully used in pine plantations. The results were disastrous, as when flushing began, several unusual symptoms, such as longitudinal splitting of bark, bark peelingoff, swollen leading shoot, collapse of apical bud, death of leading shoot, and deformed leaf, were observed. This culminated in the death of many individual trees. Thus, it is most important to determine the correct type of weedicide or arboricide and the correct time and method of application for a particular species, as the effect varies with species.

7.6 Use of fertilizer in the field

Generally, the question of applying fertilizer arises only when the site available is not fertile enough for the species to be planted. It has been found that application of fertilizer at the time of planting is effective only where there is a serious deficiency of one or more elements in the soil (Stuart-Smith, 1967). However, some species e.g. eucalyptus, can achieve additional growth even where the soil fertility was already high (Pryor, 1967). Soils of the coastal lowlands used for exotic pine plantations in Queensland were deficient in phosphate (Hawkins and Muir, 1968). This was checked by applying Nauru rock phosphate, which gave a very good response.

Applications of fertilizer to teak in plantations have not proved beneficial (Ventkataramany, 1956; Briscoe and Ybarra-Coronado, 1971). Briscoe and Ybarra-Coronado in Puerto Rico, treated a three to sixteen year old teak plantation under 17 different combinations of ammonium sulphate, superphosphate, potassium sulphate, limestone, and magnesium sulphate. The object was to study the effect of nitrogen, phosphorus, potassium, calcium and magnesium on growth of teak. To facilitate the comparison, all the plots, including one control plot were thinned to prevent intense competition obscuring treatment effects. Although phosphorus and potassium increased the growth rate of teak significantly, it was also noticed that the effect of the thinning on the increment in basal area was more marked (51 per cent superior than the unthinned) that the effect of fertilizer (53 per cent superior than the unthinned). Thus, when the effect of thinning (51 per cent) was removed, the effect of fertilizer appeared to be comparatively very small. Similarly, work carried out in India also indicated that although teak will respond to fertilizer, it was rather doubtful whether it will be economically sound to apply fertilizer in teak plantations (Venkataramany, 1956). Thus, unless the site available is not sufficiently fertile for the species the application of fertilizer in teak plantations may not be necessary.

7.7 Discussion

Careful examination of the processes for establishment of teak plantation is needed. The taungya method of regeneration is most suitable in countries where population is great and the demand for land is high.

The taungya method however may prove inadequate for large areas. In this case planting by paid labour will be necessary with consideration being given to machine planting. This type of planting should be particularly suitable for teak. Moreover, if mechanized extraction is also desired, a change to mechanized regeneration appears inevitable.

How far the other operations of site preparation for planting, tending, thinning, and extraction can be mechanized remains to be determined. There will be no problem where the area to be planted is flat or has a gentle slope, but in places with steep topography, uses of tractors and other mechanical operations will be limited. Such areas may have little use for plantation forestry.

CHAPTER VIII

METHODS OF MANIPULATING THE QUALITY AND QUANTITY OF TEAK TIMBER IN PLANTATION

8.1 General

Teak plantations in Burma have been established more for quantity than quality. To date, little attention has been paid to the quality of timber to be produced by a plantation. However, as already noted (section 1.3), the success of teak grown in plantations in many tropical countries could pose a serious threat to the Burmese teak markets in the future. To maintain Burma's position as leader in the world teak market, it is necessary for Burma to consider production of high quality teak in plantations, rather than concentrate entirely on quantity.

To produce quality teak, the desirable characteristic sought by the markets must first be determined. Attempts to produce these desirable characteristics may then be initiated relying particularly on silvicultural techniques and later on tree breeding.

8.2 Desirable characteristics in individual stems of teak

Teak is highly prized in world markets because it is both a high quality and an all purpose utility timber (Myint Aung, 1967). It is noted as especially suitable for ship decking, making door and window frames in construction and furniture making (Howard, 1948; Streets, 1962). This requires both sawn timber and veneer. Thus, it is desirable to establish teak plantations which will produce timber with qualities suitable for these dual purposes.

The properties required have been defined by Kedharnath and Matthews (1962), and Rudman _et al._, (1966). These authors considered it important to have teak wood with high durability, low shrinkage, straight grain, good strength, and good appearance. Reaction wood is therefore undesirable as it is associated with abnormally high longitudinal shrinkage and thus affects both strength and durability.

The general basic density requirements for veneer have been defined by Nicholls (1967). The optimum basic density for the production of sliced 1.5 mm veneer is 0.40 gm/cc, and the basic density range within which satisfactory furniture grade veneer is obtained lies between 0.28 gm/cc to 0.55 gm/cc. These are very broad limits and timber within this range would also be suitable for utility purposes.

Wood strength of teak is known to deteriorate when the growth rate is very fast, producing less than two rings per cm. (Laurie and Griffith, 1942; Mukerji and Bhattacharya, 1963). Specimens of fast grown teak (one ring per cm) examined showed very thin cell wall under these conditions (Laurie and Griffith, 1942). The basic density of this timber was not specified, but presumably would be outside the range suggested by Nicholls.

Teak timber contains a high concentration of quinones and related extractives which have both antitermitic and and antifungal activities (Rudman _et al._, 1966). Da Costa _et al._, (1958) found the termite resistance of the outer heartwood was significantly correlated with the average extractive content of the heartwood as a whole and also that termite resistance of the outer heartwood increased with age of the tree. It is therefore desirable to produce more heartwood during the later years of a tree's life than during the juvenile stage. This is also important from the point of view of improving mechanical properties because the core formed during a teak tree's early life is non-durable (Rudman *et al.*, 1966).

Wood qualities however are necessarily dependent upon the morphological characteristics of the tree. Many authors have attempted to relate the timber requirements of a species to the type of tree which is desirable in the field (Zobel, 1964; Nicholls, 1967).

Stem straightness is widely acknowledged as most important factor in determining the wood quality. Zobel (1964) stated a general improvement in stem straightness of trees automatically improves the quality of the wood for any use to which it will be put. Similarly, Nicholls (1967) concluded that in most tree species, the improvement of stem form in terms of straightness, taper, and bole roundness confers benefits of great returns of sawnwood and quality veneer. Thus, it would be desirable to have trees with good form in plantation.

Kedharneth and Matthews (1962) defined the desirable characteristics for teak trees as a good growth rate in both height and diameter; superior form factor;; straight and clean bole free from excessive buttressing, fluting spiral grain, and epicormic branches; well developed crown; flattened to moderately ascending branches; resistance to the leaf defoliator and leaf skeletonizer. Laurie and Griffith (1942) qualified the need to avoid epicormics. Short lived epicormics are unlikely to cause serious defects in timber and may even improve it by giving some figure or ornamental grain. However, Laurie and Griffith agreed that persistent epicormics will cause knotty and unclean timber and are undesirable.

Cameron (1966) similarly defined the desirable characters required for individual teak trees to be used in a breeding programme for Papua New Guinea as follows:-

(1) Late flowering type: i.e. flowering does not occur until the trees are seven to ten years old.

(2) Must show superior rates of diameter and height growth.

(3) Branches should be flat, slightly ascending and of small diameter.

(4) Branches on merchantable bole should be shed rapidly.

(5) Crown should be comparatively narrow with a low ratio of crown diameter to stem diameter.

(6) The boles should be free of sweeps and kinks, with no fluting and little buttressing.

(7) The bole should taper slowly, and timber grain must be straight.

(8) The tree must show a high degree of resistance to butt rooting fungi.

(9) Timber must be of superior quality in terms of strength, hardiness, shrinkage, termite and fungal resistance, figure and colour.

(10) Production of large viable seed should be regular and profuse, though not at the sacrifice of flowering age.

In Burma and India where the black stripe teak occurs, trees with this feature should also be selected for use in the tree breeding programme.

The high quality requirement by teak appears to be particularly emphasized in these lists of desirable qualities. Cameron's statement of the need for the late flowering trees to obviate the deformation caused by terminal flowering (see Chapter V) appears particularly important. The importance of avoiding losses due to butt rotting and termites also receives strong emphasis. Thus, the qualities required in teak trees designed to produce high quality sawn timber can now be briefly summarized. Beside the usual requirement of stem with good straightness and vigour, attention must also be paid to late flowering, branching and epicormic production. The basic density of the heartwood should be as close to 0.40 gm/cc as possible and within the range 0.28 gm/cc to 0.55 gm/cc. The heartwood should have a high extractive content. To facilitate this and to avoid a large juvenile core, early diameter growth should be slow and later growth as fast as possible.

8.3 Factors affecting expression of the desirable characteristics

The morphological characters of individual trees and hence the wood qualities are determined by the interaction between genetic make up of the trees and the environmental conditions under which they develop (Wright *et al*.,1958; Larsen, 1963; Morandini, 1964; Zobel, 1964; Kedharnath, 1967). Although both the environment and the genetic constitution are largely predetermined, they can be modified by foresters either by silvicultural procedures or by tree breeding. Silvicultural procedures modify the local micro-environment and thus manipulate the growth patterns, the morphology and the wood quality of established trees. Tree breeding procedures modify the genetic constitution of the trees prior to establishment and endeavour to produce trees which will perform well and give high quality timber under the local conditions. Both these methods can be applied to teak plantations. The possible silvicultural procedures are discussed below and the possibilities for tree breeding of teak are detailed in Cahpter X.

8.4 The effect of silvicultural treatment on wood quality

Generally, silvicultural operations are primarily intended to promote the growth rate of the stand. But as wood properties are affected by the physical environment, silvicultural treatments can also be used to control wood quality. With species used for high quality timber, it is important therefore that wood quality should also be a major silvicultural consideration. Spacing, and thinning regimes, and pruning and fertilizing are all known to affect wood quality.

8.4.1 Initial spacing

With close initial spacing, trees generally are compelled to grow straighter with relatively more foliage on the leaders and topmost laterals (Anderson, 1958). This results in trees with high crown and clean bole. Closer initial spacing will also reduce weed competition. Wide spacing is known to assist the development of big and persistent branches low on the bole. These generally become absorbed within the wood to form live knots, and if these coarse branches die, their bases become embedded in the wood, forming peg knots (Anderson, 1958).

In teak plantations in India and Burma, initial spacings of 1.4 x 1.4m, 1.8 x 1.8m, 1.8 x 3.7m, 2.7 x 2.7m, and 3.7 x 3.7m have been tried (Laurie and Griffith, 1942). The spacings wider than 1.8 x 1.8m were tried with the object of economizing on the number of teak seedlings, planting costs, thinning costs, and also to obtain fast initial growth. However, the 1.8 x 1.8m spacing was found to be the most economic when all early weeding and cleaning costs were considered, as early crown closure reduces weed competition (Laurie and Griffith, 1942). Teak growing in Tanzania with wider spacing than 1.8 x 1.8m was observed to have developed coarse branching (Wood. 1967).

As noted above, teak possess a non durable core and the termitic resistance of the outer heartwood increases with the increasing age of the tree. Both these factors make it desirable to have less wood in the early age of teak trees, thus, a close initial spacing is desirable. However, many countries growing teak in plantation adopt the initial spacing of 1.8 x 1.8m (Laurie and Griffith, 1942; Beard, 1943; Kadambi, 1945; Wood, 1967; Persson, 1971). From the wood quality point of view, it is evident that closer initial spacing might be desirable. The costs and the effects on wood quality of using initial spacings closer than 1.8 x 1.8m are therefore worth consideration.

8.4.2 Thinning

Since thinning involves the manipulation of the crown of trees, it should also be possible to use as a tool to improve wood quality in a stand. According to Larson (1963), the size of a tree's crown in relation to the length of the bole determines wood quality. A dominant tree with an unusually large and vigorous crown will produce relatively wide bands of earlywood, whereas when a dominant with a vigorous crown has a relatively long clear bole, the band of latewood produced is relatively wider. Also, suppressed trees having relatively small crowns usually possess higher percentages of latewood and thus have denser wood than the larger crowned dominants. Generally, in young stands, the increase in crown size of the new dominants after thinning is usually followed by increase in the proportion of earlywood. In older stands however, both earlywood and latewood usually increase simultaneously and uniformly, and wood with wider growth rings, but with little or no change in quality is obtained (Larson, 1963).

In a comprehensive study of Eucalyptus regnans Higgs (1966) stated that generally, thinning is followed by a healthier crown development, expansion of the crown and root systems, a more continuous growing season, more light and greater water and nutrient supplies. Clearly therefore, the development of wider growth rings would be expected after thinning. Higgs found the species responded to thinning by increasing average fibre length, and average wood density, as well as average ring width. He, however, could not find any correlation between ring width and fibre length, nor ring width with wood density, and he concluded that changes in wood properties do not result from changes in diameter growth.

Higgs' findings confirmed earlier work on teak by Nair and Mukerji (1957) in India. These authors examined naturally grown teak, sampling each tree at several positions. The results of their studies are detailed in Table 27. Clearly, within the range of growth rates sampled, (3.2 - 7.2 rings per cm), there is no effect on the wood properties studied. However, all the specimens assessed had growth rates below two rings per cm. Deterioration in wood properties might be observed if specimens with growth rates greater than two rings per cm should be examined.

Care must be taken to ensure teak stands are not under-thinned. There is some evidence that teak plantations retained in an overstocked condition for a lengthy period fail to respond to thinnings. Experience in Burma indicated

Table 27 Properties of teak wood from different localities as given by Nair and Mukerji (1957)

Province	Locality (Division)	No. of trees	No. of rings per inch	Specific gravity	Maximum crushing stress lb/sq.in.	Modulus of rupture lb/sq.in.	Modulus of elasticity 1000 lb/sq. in	Maximum height of drop in inches
Bombay	North Kanara	5	8.7	0.555	5340	10950	1510	35.6
"	North Kanara (girdled)	5	12.5	0.560	4740	9500	1340	30.8
"	North Kanara (ungirdled)	5	13.8	0.523	4560	9350	1305	32.3
	West Thana	5	8.1	0.576	5390	10950	1445	38.7
Burma	Pyinmana	5	9.1	0.613	7530	14350	1950	41.4
"	Zigon (girdled)	4	8.7	0.593	6460	12100	1810	36.9
"	Zigon(ungirdled)	5	9.2	0.591	5710	11600	1655	34.5
Madhya Pradesh	Hoshangabad	5	11.9	0.559	5270	10500	1410	36.6
	South Chanda	5	13.6	0.524	4440	9050	1205	27.7
Madras	Malabar	5	11.9	0.612	5400	10700	1570	31.8
"	South Coimbatore	5	18.3	0.640	6350	12550	1480	34.3

that teak plantation kept underthinned for the first 20 years did not respond to heavy thinnings (Moore, 1966). Underthinned plantations suddenly opened up also generally respond by the production of epicormic branches (Laurie and Griffith, 1942). Trees which are whippy due to overcrowding are liable to serious wind damage when suddenly opened up. The author has observed wind damage in a heavily eroded teak plantation in Pyinmana Division, Burma, which was thinned heavier than the normal thinning grade only long after it was due. Overstocking in teak plantation also results in the depletion of the undergrowth followed by serious soil erosion.

Thus, with teak plantation, it is generally desirable to keep the non durable core as small as possible. The species should therefore be initially closely spaced and then opened up slowly and gradually. A reasonably heavy and regular thinning is desirable in the later years to give high production of high quality wood. Attempts to follow these procedures require considerable expertise in silvicultural management. When thinnings are delayed, severe problems result. Overstocked or neglected plantations may produce severe erosion; if the overstocking is severe they may fail to respond to thinning. There is a danger of a reduction in wood quality due to epicormic production if the heavy thinnings are applied and there is also a danger of wind damage in such situations.

Teak plantation management therefore requires great care. Silvicultural operations need to be carried out regularly and on schedule. Growth, and wood properties, can be affected if the required silvicultural operations are delayed or overlooked, and soil erosion is a serious hazard of overstocked plantations.

CHAPTER IX

VARIATION IN TREE SPECIES WITH PARTICULAR REFERENCE TO TEAK

9.1 Nature of variation

9.1.1 Genotype x environment interaction

Variation in a tree species is due to variations in both the genetic make up of the individuals of the species, and in the environment (Turesson, 1923; Clausen and Hiesey, 1958; Heslop-Harrison, 1964; Zobel, 1964; Langlet, 1967). The expression of every character in a particular species is potentially controlled by the genotypic constitution of the individuals, whilst the eventual phenotypes produced are due to the reaction of the genotypes with the environment, (Turesson, 1922a; Burley, 1965). The genetic processes of mutation, recombination, and natural selection, change the frequency of genes in natural populations and lead to the development of variation patterns (Burley, 1965; Squillace, 1966; Morgenstern, 1969). These react with the environment, and genotypes poorly adapted for a particular locality are selected against, and eventually disappear. The result is a variation from locality to locality in the frequency of many characteristics common to individuals of a particular species (Burley, 1965; Florence and Malajezuk, 1971). Langford and Buell (1969) considered the combined action of genetic variation and natural selection to be a divisive process acting on the variable individuals in a population. From this divisive process, more and more discrete units emerge from any earlier unit, each adapted more precisely for a narrower range of environmental conditions than the earlier unit.

The process has been summarized by Dobzhansky (1964),

> 'The adaptiveness of organisms to their environment is striking. The structures, functions and mode of life of every species are at least tolerably consonant with the demands of its environment. Every organism is adjusted to occupy and to exploit certain habits. But habits vary in space. Evolution has, accordingly, brought about the diversity of allopatric organisms, which inhabit different territories which are accessible to an individual organism in its wandering during life time, or in which sex cells or seeds of an individual are dispersed. Adaptation to such local diversities of habitats brings about diversity of sympatric organisms'.

Movement to different environments may cause previously hidden variability to be expressed (Clausen and Hiesey, 1958). This was demonstrated by Mergen *et al*.,(1967)using seedlings of 50 provenances of jack pine (*Pinus Banksiana* Lamb) to study five characters under 12 environmental conditions. They found whilst a particular environment allowed the demonstration of seedling differences in, say, character 'A', but not in 'B', the situation could be reversed in other environments. Similarly, the classic work of Turesson (1922a) on *Hieracium umbellatum* from three different habitats showed hereditary differences masked by natural habitat factors were readily revealed when the types were cultured in a uniform environment. Mergen *et al*. also noted that the geographic variation of jack pine tended to be more pronounced under the extreme environmental condition of short daylength.

9.1.2 Variation throughout species range

Many tree species occur over a wide range encompassing a large number of locally different environments. Such species frequently display geographic differences in one or more important characteristics. Squillace (1966) in his study on slash pine (*Pinus elliottii* Engelm.) found most of the characteristics studied (including seed yield, germinability and speed of germination, total height, stem diameter stomatal measurements) showed significant differences associated with the geographic source of the material. Similarly Luckhoff (1964) found *Pinus caribaea* from Bahamas, Cuba, and Central American mainland, formed three well defined geographic variants with a distinct latitudinal trend, and supported the sub-division of the species into three separate taxonomic entities.

Much of the variation in a wide ranging species can be attributed directly to climate. Thus, Wright (1962) generalized that southern provenance compared to a northern provenance of the same species is usually

(i) faster growing

(ii) less susceptible to late spring or early autumn frosts

(iii) more susceptible to damage by winter cold

(iv) less apt to show autumn coloration and

(v) capable of growing longer in autumn.

Wright also generalized concerning edaphic factors, noting that a moist site population compared to a dry site population is usually

(1) faster growing

(2) smaller seeded, and

(3) less deeply rooted.

Squillace (1966) in his work on slash pine also found that variation among individuals in a population of the species is less in the central areas and greatest at the extremities of the species range. Squillace believed the greater variability of genotypes in the extremities of the species range to be due to greater fluctuation of critical environmental factors in these regions.

Variation through the species range may be clinal (continuous) or ecotypic (discontinuous). Since climatic factors change gradually along geographical or altitudinal gradients, the resulting variation pattern is normally clinal (Critchfield, 1957; Squillace, 1966; Langlet, 1967; Butjenen and Stern, 1967). Eldridge (1964, 1966, 1968), working on _Eucalyptus regnans_ from Mount Erica, Australia, found existence of clinal altitudinal variation for the species. Clinal latitudinal variation in many characters of slash pine was also recorded by Squillace (1966).

However, discontinuous habitats can result in discrete populations or ecotypes (Squillace, 1966). The sub-division of _Pinus caribaea_ noted above provides a good example of a tree species divided by discontinuous variation, in this case a result of geographical separation by oceans.

Pockets of ecotypes may also occur in a great stretch of a continuously variable species (Pryor, 1963; Heslop-Harrison, 1964). Squillace (1966) considered such a combination of both clinal and ecotypic variation can result from either past or present isolation.

9.1.3 Causes of variation

Variation in tree species is caused by natural selection acting on genotypes. Climatic factors are often important natural selection forces, and therefore, frequently play an important part in determining the variation of tree species.

Climate exercises its control on the performance of tree species mainly through the agencies of temperature, light and water (Callaham, 1962; Treshow, 1970). The effects of these climatic factors on the response of tree growth and their importance have been demonstrated by many research workers in this field (Kramer and Kozlowski, 1960; Callaham, 1962; Downs, 1962; Mergen *et al*.,1967; Slee, 1968; Eldridge, 1969; Morgenstern, 1969a, 1969b).

Temperature: Temperature controls the rate of all growth processes and sometimes also influences growth period (Kramer and Kozlowski, 1960; Callaham, 1962). This is effected through its influence on physiological activities by controlling chemical reactions (Treshow, 1970). Tree species normally can grow under wide temperature range, but have limits above and below which the physiological functions cease, and also an optimum temperature range within which the plant grows best (Callaham, 1962; Treshow, 1970). Growth decreases as the temperature is varied from the optimum, and completely ceases when varied beyond its extreme limits. Response to temperature variation however varies with species and with provenance (Kramer and Kozlowski, 1960; Callaham, 1962). Kramer and Kozlowski (1960) believed that species are arranged in altitudinal and latitudinal zones, with the individuals within each zone closely adapted to the temperature regimes of the zone. Callaham, working on ponderosa pine from three provenances found the first provenance required high temperatures for good growth, the second cold days and hot nights, whilst the third grew reasonably well at lower night temperatures.

Temperature therefore plays a most important part in determining the pattern of growth and distribution of tree species.

Light: Light is another important factor of the climate, the duration, intensity and quality of which determine plant growth (Kramer and Kozlowski, 1960; Callaham, 1962; Treshow, 1970). Light energy radiation with wave lengths 400 - 760 mμ is required directly to sustain growth of all green plants (Treshow, 1970). Light intensity influences tree growth through a direct effect on photosynthesis, stomatal opening and chlorophyll synthesis. Natural variations in quality or wave-length of light are generally too small to be of any physiological importance (Kramer and Kozlowski, 1960).

The duration of the light period (photoperiod) is known to be of importance (Kramer and Kozlowski, 1960). Photoperiod has been shown to influence flowering, cambial activity, internode elongation, dormancy and other plant developmental processes (Kramer and Kozlowski, 1960; Callaham, 1962; Downs, 1962; Treshow, 1970). Under experimental conditions, Downs recorded larch and many southern pines stop growth at 12 hours or less of photoperiod, sitka spruce (*Picea sitchensis* [Bong.] Carr) at 14 hours or less, and Norway spruce (*Picea abies* [L.] Karst.) and white spruce (*Picea glauca* [Moench.] Voss) at 16 hours or less.

Water: Water also has a strong influence on plant development. In plants water maintains cell turgidity, provides a substrate and medium for chemical reactions and transport of mineral ions (Treshow, 1970). Treshow (1970) also believed that when transpired from leaves, water acted to maintain the plant at a temperature suitable for metabolic reactions. The internal water balance of a plant is determined by the relative rates of absorption and transpiration, and is thus controlled by both the soil and atmospheric moisture conditions (Kramer and Kozlowski,1960). Water requirement varies with species. For some species suggestions as to detailed water requirements have been postulated. For example, *Pinus elliottii* is thought to require at least 250 mm rainfall in early spring. Growth of the species declines in areas without such a rainfall regime (Squillace and Kraus, 1959; Slee, 1968). Similarly, the requirement of a definite dry season for normal teak growth (sub-section 4.2.1) indicates the need of the species for a particular moisture regime.

9.1.4 The importance of variation to forestry

Variation in tree species assumes considerable importance in the establishment of plantations. If one geographic locality (provenance) gives timber of superior quality or size than others, then clearly the material should be used if possible. Determination of the most suitable provenance is not a simple or quick procedure. It is first necessary to establish the existence of variation in important characters in the species concerned, and secondly to determine which seed source is the best considering all possible combinations of desirable characters. This may be done by a provenance trial in which material from all possible localities is grown and compared in various plantation areas. The value of such a provenance trial is undisputed, but the process is lengthy. To save time seed is frequently collected from an environment more or less homologous to that in which the plantation will be established, on the assumption that this will provide the best-adapted material. It would facilitate such environmental matching if the major factors controlling variation within a particular species could be isolated. Such studies certainly require controlled environment facilities and may need to be done in considerable detail to enable extrapolation from the laboratory to the field.

Some provenance studies of teak have been established in the field, but the factors determining the variation within the species are unknown. Consequently, after reviewing the studies of variation in the species, it was decided to initiate some preliminary studies of the major climatic factors affecting seedling variation in the species.

9.2 Variation in Teak

Several broad studies have examined geographic variation in teak, and the existence of such variation within the species is well established (Beard, 1943; Mathauda, 1951; Wyatt-Smith, 1961; Keiding et al.,1964; Cameron, 1966; Maung Gale (2) and Nyunt Naing, 1967; Hedegart, 1971b; Persson, 1971). Information however is still incomplete. Most of the work has only been able to demonstrate the existence of variation within the species.

Persson (1971) conducted a very good trial at Kihuwi, Tanzania. He used open-pollinated seeds from selected trees in established plantations at three Tanzanian localities (Kihuwi, Bigwa, Mtibwa). The progenies were outplanted using a randomized block with four replications which allowed comparison between the three provenances as well as between the progenies. Studies were made of height and diameter growth and also of various morphological features known to affect timber quality, namely height to the base of first living branch, straightness, and fluting and forking of the main stem. Total height was measured every year until the assessment at age four when diameter at breast height (1.4 m) was measured. The assessment of the other features was made at age three years six months. In these assessments each character was assessed subjectively and numerical values were applied according to specified scales. Details of the provenances and the results are given in Table 28.

Table 28. Results of teak progeny trial at Kihuwi, Tanzania as given by Persson (1971)

Provenance	Latitude	Altitude (m)	Rainfall (mm)	Mean Height	Basal area/ha	Straightness(1)	Fluting (1)
Kihuwi	5°12'S	200	1400	12.5	20.06	1.220	1.235
Mtibwa	6°08'S	460	1200	12.4	18.46	1.147	1.120
Bigwa	6°05'S	580	950	11.8	18.25	1.135	1.072

(1) Higher value indicates more crookedness or fluting. The significance of the differences were calculated at 5 percent level. Bars link differences not significant at 5% level.

The results indicated the local provenance was superior to the others in volume production (mean height and basal area) but poorer in timber quality (stem straightness and fluting). Rainfall, altitude and latitude all varied from provenance to provenance, although the latitudinal change was small (less than 1°) and possibly of little importance. The major environmental factors may also have varied with provenance. For example, temperature is associated with altitude and the mean temperature decreases by between 0.4°C and 0.7°C for every ascent of 100m in altitude in the tropics (Richard, 1964). Thus, adaptation to temperature or to rainfall could be considered as causing the difference.

The relationship between rainfall of the provenances and their performance was in agreement with the behaviour of teak in natural forests. Teak in the semi-evergreen forests are normally large, but badly fluted, whereas teak in the drier deciduous forests are smaller and less fluted (see Chapter II).

In Trinidad, Beard (1943) studied the differences between teak from coastal localities of Travancore, India (9°S), and Tenasserim, Burma (16°S). The Indian provenance was thinned and measurements of height and volume production taken at the age of six. These were compared with equivalent figures from three sample plots of the teak originating from the Burmese area established in local plantations on similar soil types within a radius of half a mile. Beard also assessed stem straightness and form factor. The Indian provenance was markedly inferior in height growth, total volume, mean annual increment, form factor and straightness (Table 29). Beard also found marked vegetative differences between the provenances. The Burmese provenance had bigger leaves and shorter petiole (Table 29). The leaves of plants of the Indian provenance were shiny and smooth, whereas those of Burmese origin were rough.

Table 29. Comparative data for Indian and Burmese provenances as given by Beard (1943)

Criterion	India	Burma
Total height (m)	9.8	12.8
Volume under bark (m^3/ha)	16.1	21.9
Mean annual increment (m^3/ha)	3.8	4.4
Form factor	0.156	o.204
Leaf size (cm)	23-27 x 11-15	51-70 x 38-41
Petiole length (cm)	3.8	2.5

No definition of a form factor was provided by Beard. The values quoted appear too low for the more common usage of the term, i.e. the ratio of tree volume to the product of tree height and basal area. Accordingly, these results for form factor can only be used in general terms.

In 1930, a comprehensive teak provenance trial was established in India on an inter-state basis according to Mathauda (1951). Included were 11 seed sources, of which two were Burmese, and the remainder Indian. The trial was established in 13 different centres, but at only two (Nilambur and South Coimbatore) did Mathauda feel the design and layout of the trial were satisfactory. At other centres, the trials were not adequately randomized or replicated, and were considered to be statistically unsound. Mathauda summarized the overall results paying particular attention to those from the two localities with an adequate layout.

At Nilambur (11°N), near the west coast in the wet part of India, six provenances (Nilambur, Anamalais, Travancore, South Bombay, South Burma, and North Burma) were included. All were planted in the same year except the Northern Burmese material which was planted one year later. This provenance also suffered severely from monkeys damaging the young terminal shoots of the trees. The diameter, height, and total volume per acre were measured at the age of four, nine, and fifteen years. The results were as given in Table 30.

At age four years, North Burma provenance was significantly the poorest in height measurements. No significant differences at the 5% level were observed in diameter and volume measurements.

South Bombay was significantly the best and North Burma the poorest in all characteristics at age nine. Anamalais was as poor as North Burma in height growth at this age, although not significantly different from other provenances in diameter and volume measurements.

At age 15 years, South Burma and South Bombay provenances were significantly the best in all respects. Anamalais provenance was significantly the poorest in diameter measurements and North Burma in height measurements.

Thus, in all the characters measured South Bombay and South Burma provenances gave the best performance, while North Burma origin was the poorest, but it is of course invalid to compare North Burma with other origins in this experiment, due to the problems with this provenance.

Trials carried out in South Coimbatore (11°N), which is further inland, included only four provenances [South Burma, Mount Stuart (local), Mysore, and Nilambur]. These were planted in randomized block design in 1934. At age

Table 30 Results of provenance trial carried out in Nilambur as given by Mathauda (1951)

Provenance	4-year			9-year			15-year		
	Average Diameter (cm)	Average Height (m)	Total Vol. (m^3/ha)	Average Diameter (cm)	Average Height (m)	Total Vol. (m^3/ha)	Average Diameter (cm)	Average Height (m)	Total Vol. (m^3/ha)
Nilambur	5.6	6.4	15.6	9.4	11.0	50.0	14.7	15.5	59.1
Anamalais	5.3	6.4	14.8	8.9	10.1	41.3	13.5	14.0	54.3
Travancore	5.6	6.4	19.0	9.4	10.7	50.4	14.5	14.3	56.9
South Bombay	5.8	6.4	18.1	10.4	12.5	61.2	16.8	17.1	76.2
South Burma	6.1	6.4	18.3	9.9	11.6	52.1	16.8	16.5	77.7
North Burma	5.3	5.2	10.6	8.9	9.1	32.9	13.7	13.1	52.1

the non-local provenances at Nilambur. In this wet tropical region, the Southern Burmese and Southern Bombay provenances have a standing volume approximately 30 percent greater than any other material.

In a summary of genetic improvement of teak in Papua New Guinea, Cameron (1966) recorded preliminary findings from an unreplicated provenance trial of teak in that area. Three provenances were included in the trial which was intended only as a guide for later trials. He used materials from Madras (India), Trinidad (Burmese origin) and local (also believed to be Burmese origin) which were planted in two localities (Keravat and Mount Lawes). Keravat is a high rainfall area (2,870 mm of mean annual rainfall), with every month of the year receiving at least 150 mm of rain. Mount Lawes has a marked dry season and a mean annual rainfall of 2,000 mm (Anon. 1970c; Anon.(n.d.). Preliminary assessment (details of age were not specified) showed the Madras strain was superior to the others in log length, bole cylindricity, and the small amount of buttressing or fluting. The timber of the Madras strain was also darker in colour. The Trinidad and local materials were similar in appearance and performance, though the Trinidad strain tended to be slightly superior in some characters.

Teak provenance trials carried out by the Thai-Danish Teak Improvement Centre in Thailand were analyzed by Hedegart (1971b). For the first trial seeds were collected locally in Thailand in 1965. The trial included 30 provenances planted in a five replicate randomized block design. Height growth, diameter growth and survival percentage were assessed. Measurements made at age one year showed significant differences in height growth, but not in diameter growth or survival. Later measurements made at age two, three, four and five showed no significant difference in any of the characters studied.

A second seed collection was carried out in 15 local Thai provenances in 1968. To this was added one exotic Indian provenance. The seeds were sown in a 10 x 100 seeds replications randomized block design. The seedlings were planted as stumps in four field trials situated in the provinces of Chieng Rai (19°03'N latitude and 440 m altitude), Uttaridit (17°43'N latitude and 100 m altitude), Nakhon Ratchasima (14°40'N latitude and 200 m altitude), and Chantaburi (13°00'N latitude and 200 m altitude). Studies were made of seed weight, seed size, seed diameter, germination, survival percentage in the field, and height growth. Considerable variation in seed weight (383 - 627 gm/1000 seed), seed size (401 - 801 seeds/litre), seed diameter (9.9 - 12.4 mm), and germination (5% - 47%) were recorded. The exotic Indian provenance gave the poorest germination. No correlation was observed between germination per cent and geographic or topographic position of the provenance.

The trial's location at Nakhon Ratchasima gave very poor and irregular survival during the first year and thus no detailed analysis was possible. Survival per cent assessed at Chieng Rai (22.9 - 66.7%), Uttaridit (60.2 - 76.4%), and

Chantaburi (13.5 - 35.3%) gave significant differences between provenances. Height measurements at Chieng Rai indicated significant differences between the provenances at age one year, but these had disappeared by the second year. Height measurements at Uttaradit (0.3 - 0.4 m) showed no significant differences either in the first or in the second year. Heights were not assessed at Chantaburi.

Thus, Hedegart's work indicated some Thai provenances varied in seed size, seed weight, germination per cent and survival per cent in the field. Variations in height growth appeared unimportant at young age.

In Burma, Maung Gale (2) and Nyunt Naing (1967) compared four exotic sources and nine Burmese provenances in trials in Southern Burma. The exotic materials were from seed collection in Indonesia and India (locations unspecified) and also from introduced materials in Togo (Dahomy) and New Guinea. The Burmese materials were from three northern (Myitkyina, West Katha, Mongmit), and six southern provenances (Pyinmana, South Toungoo, Thayetmyo, Zigon, Tharawaddy, Kawkareik). All treatments were established at three separate locations in southern Burma (Zigon, Pyinmana and North Toungoo), using a randomized block layout. Survival per cent and height growth were assessed periodically from age one to age six years. Survival varied significantly between provenances. At all three locations, the nearest local material gave a higher survival percentage than provenances which were further away (northern Burma and exotic provenances). Although the results of the height growth measurements were not statistically analyzed, there were indications of variation in height of the provenances studied and also that the comparative performance of provenances varied with locality of planting.

The work of Wyatt-Smith (1961) in north-west Malaysia also suggested that local provenance was the best. He used seed from

(i) local elite trees of first generation, material of Sumatra origin (Tree Nos.47-50),

(ii) mixed second and third generation material of Sumatra origin (Tree Nos.3, 18, 20),

(iii) local first generation material of Java origin (Tree Nos.12-14),

(iv) selected trees from Northern Thailand, and

(v) heavy rainfall teak zone of Java, and

sowed them in beds being chosen at random in a stratified manner at two locations including Changlum (6°26'N latitude), and Jeniang (5°48'N latitude). Studies were made on germination and seedling height, with germination measured up till 64 weeks after sowing and height measured on the tenth month after sowing. No statistical analyses were conducted but the results indicated provenance variation in both germination and seedling height (Table 32). Local provenances exhibited the best performance and Thailand the poorest.

Table 32 Comparison of germination and height growth of local and exotic provenances as given by Wyatt-Smith (1961)

Provenances	Germination % (1)	Height (cm) (2)
Elite Tree Nos 47-50	37.3	63.0
Elite Tree Nos 3, 18, 20	26.8	71.6
Elite Tree Nos 12-14	37.4	67.3
Java	36.7	58.7
Thailand	18.4	55.6

(1) Average for two nurseries at Changlum and Jeniang
(2) Results were given in height classes. Figures given in this table however were obtained by multiplying number of trees with their respective mean of the height classes and averaging the total height of the provenance.

Germination of the provenance from Thailand (18.4%) was very poor as compared to the remaining provenances (26.8% - 37.4%). Average height of the seedlings also indicated the inferiority of the Thai origin (55.6 cm) to those of the remaining origins (58.7 cm - 71.6 cm). The fact that Javanese provenance was comparable to the local provenances was possibly due to their similarity in latitude, except that Malaysia is in the northern hemisphere and Java in the south. Consequently, the difference in climatic condition will not be as great as between Malaysia and northern Thailand.

Widespread studies indicate the existence of provenance variation in teak in volume production, morphological characteristics that determine timber qualities, survival, and seed quality. They also indicate that the comparative performance of provenances may change with age and place, but the local provenance usually was the best, or if not, among the best. The lack of variation among the wide range of Thai provenances studied by Hedegart tends to support the proposed sub-division for provenance trials (Sub-Section 10.2.3) in which Thailand was considered as a single entity.

Clearly when plantation establishment is considered, provenance trials in as much detail as possible should be established and assessed as soon as practicable.

CHAPTER X

POSSIBILITIES FOR TREE BREEDING

10.1 General

The genetic variation present in tree species may be exploited by means of tree breeding programmes in which trees with desirable characteristics are selected and bred for the establishment of plantations containing superior genotypes. A tree breeding programme generally involves:

(1) Provenance trials established on a range of sites covering potential planting areas and studies of variation of biological and morphological characteristics between and within the provenances.

(2) Exploitation of tree to tree variation from within the best provenance by selection and testing of plus trees.

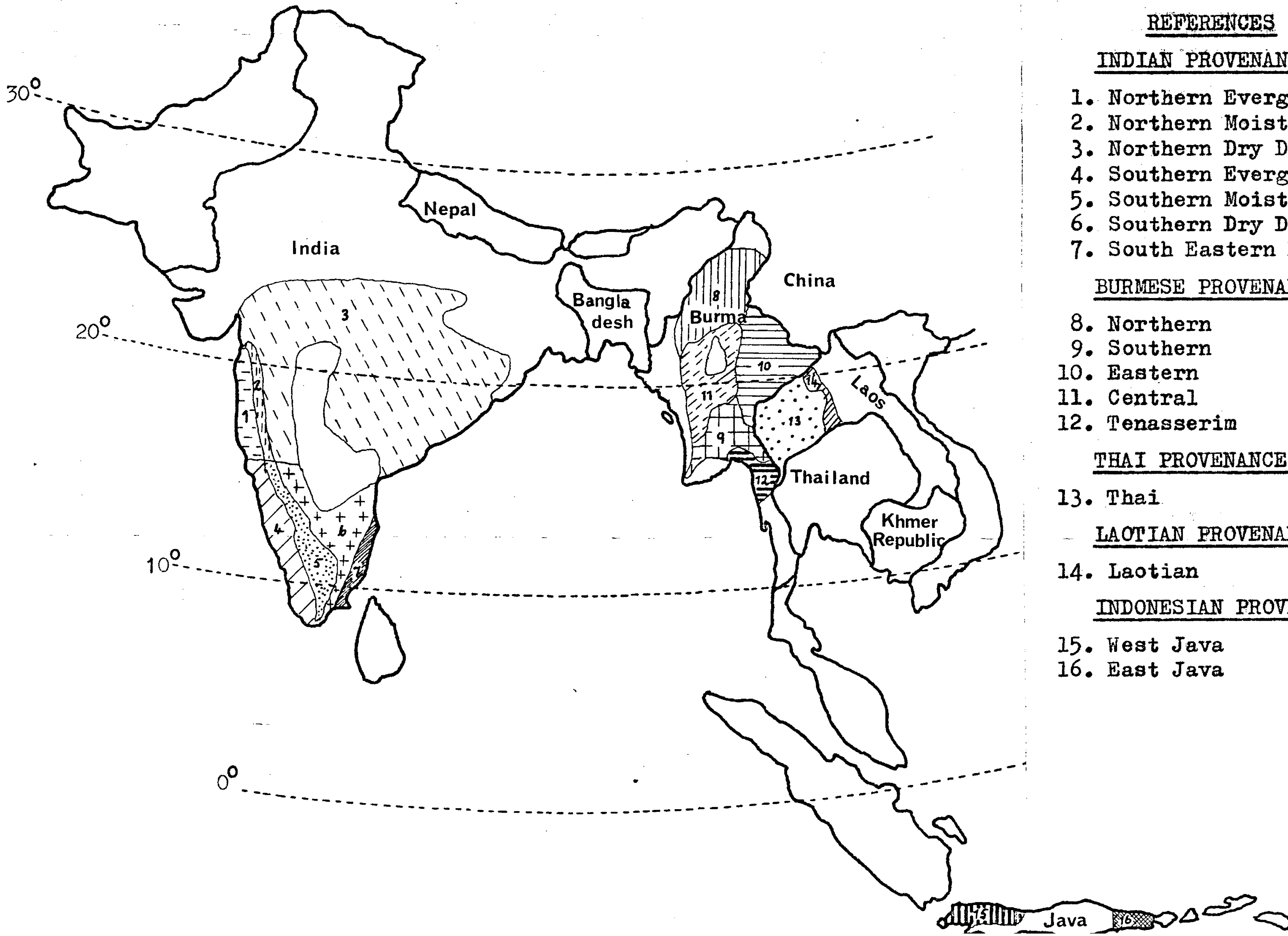
(3) Establishment of seed orchards for breeding from the selected trees.

10.2 Provenance variation and a guide to provenance collection in South East Asia

The existence of variation in teak trees has been discussed in Chapter IX. Variations in volume production, morphological characteristics that determine timber qualities, and survival were demonstrated. The comparative performance of provenances may change with age, and the local provenance was generally proved to be the best.

The trials to date have been limited in their coverage of the species range and have provided few guidelines to the selection of particular provenances for particular areas. Consequently a pressing need for any area which is to be planted

Figure 10 Proposed Teak Provenances in South East Asia.



REFERENCES

INDIAN PROVENANCES

1. Northern Evergreen
2. Northern Moist Deciduous
3. Northern Dry Deciduous
4. Southern Evergreen
5. Southern Moist Deciduous
6. Southern Dry Deciduous
7. South Eastern Evergreen

BURMESE PROVENANCES

8. Northern
9. Southern
10. Eastern
11. Central
12. Tenasserim

THAI PROVENANCE

13. Thai

LAOTIAN PROVENANCE

14. Laotian

INDONESIAN PROVENANCES

15. West Java
16. East Java

with teak is for a widespread provenance trial to be instituted. This trial should encompass as many areas of natural occurrence of the species as possible. A tentative outline to determine the absolute minimum number of provenances for such a study follows.

10.2.1 Burma

Using climatological data, Burma can broadly be divided into the five provenances shown in Figure 10, namely:-

(i) The Northern Provenance

(ii) The Southern Provenance

(iii) The Eastern Provenance

(iv) The Central Provenance

(v) The Tenasserim Provenance

The rainfall and temperature ranges typical of these regions have been broadly summarized in Table 33. This table was prepared using materials and rainfall map in Anon (1952) and Anon (1966). The forest divisions included in each region are detailed in Appendix II.

Table 33. Climatic data for proposed provenances in Burma

Provenance	Rainfall (mm)	Temperature (°C)	
		Min.	Max
(i) Northern provenance	1520 - 2160	17	28
(ii) Southern provenance	2030 - 4570	22	31
(iii) Eastern provenance	1270 - 2030	14	25
(iv) Central provenance	less than 1270	21	32
(v) Tenasserim provenance	1830 - 5080	25	30

(i) Northern Provenance. This provenance represents the northern limit of the natural occurrence of teak. Consequently effects of temperature and latitude may be expected to be most pronounced in this region. Teak from this area should be considered for all cooler areas, particularly at high latitudes. For rainfall distribution and monthly temperature of the area, see Myitkyina in Figure 8.1

(ii) Southern Provenance. The area where the best quality Burmese teak occurs. The climatic conditions is considered ideal for teak. A combination of good growth and good timber quality would be expected from this provenance which should be included in most widespread provenance trial of teak. See Toungoo, Tharawaddy, and Rangoon in Figures 8.2 and 8.3 for more detailed climatic conditions.

(iii) Eastern Provenance. This provenance is situated furthest inland and on a plateau called the Shan Plateau. Consequently it is cooler, and a demonstration of the effect of this lower temperature is anticipated from this area. With the northern provenance, this area should be included in trials for latitudinal and altitudinal extremes for teak. For detailed climatic data, see Lashio and Taunggyi in Figure 8.1.

(iv) Central Provenance. A fairly dry part of the country with rainfall less than 1,270 mm. Trees in this area are not generally large, but are of good timber quality. Black stripe teak also occurs in this region. This provenance should be included in all studies for dry areas. See Mandalay, Myingyan, and Minbu in Figures 8.1 and 8.2 for more detailed climatic conditions.

(v) Tenasserim Provenance. The southern limit of the natural occurrence of teak in Burma. A high rainfall area with teak trees usually large and fluted. Most of the Burmese seed exported has come from this region due presumably to the ease of access (Beard, 1943; Streets, 1962; Persson, 1971). This provenance would probably be less suitable than others for areas lacking high rainfall and with low temperatures, but should be included in all trials for tropical climates. For more detailed climatic conditions, see Moulmein in Figure 8.5.

10.2.2 India

India can be divided into seven provenances using the forest type and rainfall as given by Trevor and Champion (1938). Most of these forest types have a very wide latitudinal range, in many cases over 8° (approximately 470 km). Therefore, it appears desirable to divide the sub-continent into at least two sections for provenance purpose. The area north of 16° latitude can be treated as (1) the northern provenance and that south of 16° latitude and (2) the southern provenance. For detailed provenance assessment, this broad division can then be further sub-divided by forest types and rainfall as follows, (see Figure 10).

(i)a Northern Evergreen Provenance. An area situated along the west coast of India and comprised of tropical evergreen and tropical semi-evergreen type of forest. The rainfall ranges from 1,270 mm to over 2,540 mm. Good growth can be expected from this provenance, but the timber may be fluted and not of very good quality. This provenance should be included in all studies for moist areas with latitude over 16°.

(i)b <u>Northern Moist Deciduous Provenance</u>. This area is also situated close to the west coast of India, but comprises mainly moist deciduous type of forests. The rainfall in this area ranges between 1,016 mm - 1,270 mm. Good growth and good timber quality can be expected from this provenance as moist deciduous forest normally carry good teak. This provenance should be included in most widespread provenance trials of teak in areas above 16° latitude.

(i)c <u>Northern Dry Deciduous Provenance</u>. This is a drier provenance consisting mainly of the dry deciduous type of forests. The rainfall in this area is less than 1,016 mm and this provenance should be included in all studies for dry areas at latitudes over 16°. Growth of teak is normally poor in the type of forest included in this provenance. Small, but usually cylindrical with minimum fluting timber can be expected from this area.

(ii)a <u>Southern Evergreen Provenance</u>. This is identical to the Northern Evergreen Provenance, except for the latitudinal range. Similar timber quality could be expected. This provenance should be considered for moist localities at latitudes less than 16°.

(ii)b <u>Southern Moist Deciduous Provenance</u>. Identical to the Northern Moist Deciduous Provenance but situated south of 16° latitude. Timber quality could be expected to be similar. This provenance should be included in all widespread trials of teak in areas south of 16° latitude.

(ii)c <u>Southern Dry Deciduous Provenance</u>. This provenance is situated south of 16° latitude and contains the same forest type, and has the same rainfall range as the Northern Dry Deciduous Provenance. Thus performance similar to the Northern Dry Deciduous Provenance can be expected. This provenance should be included in trials for dry areas below the latitude of 16°.

(ii)d <u>South Eastern Evergreen Provenance</u>. This area is situated on the east coast of India and composed mainly of tropical evergreen forest type. The rainfall range is between 1,016 mm - 1,270 mm. Although this provenance carries tropical evergreen forest type, the rainfall is low. Thus, teak with good growth and reasonably good timber quality could also be expected from this area. This provenance should be included in trials for areas within the rainfall range mentioned, particularly with latitude less than 16°.

10.2.3 <u>Thailand</u>

Information on teak forest in Thailand is very scanty. However, the area of natural occurrence (approximately 30,000 km^2) is comparatively small (see Figure 5). Trials to date in Thailand have shown little important variation to exist within the area (Hedegart, 1971b; section 9.2), and the area can therefore be considered as one provenance. The Thai provenance is situated inland with approximately 1,080 mm of total rainfall (Anon, 1966). For rainfall distribution, see Chieng Mai in Figure 7.2. Growth of teak from this provenance may be poor, but a reasonably good timber quality may be expected. This provenance should be included in studies for drier inland areas.

10.2.4 Laos

The occurrence in Laos is also very limited in extent and has also been considered as one provenance (see Figure 5). The Laotian Provenance has a total rainfall of approximately 1,710 mm (Anon, 1966). The rainfall range of this provenance appears ideal for teak. Thus teak with good performance in growth and good timber quality may be expected from this area. For detailed rainfall pattern, see Vientiane in Figure 7.2. This provenance should be included in all widespread provenance trials of teak.

10.2.5 Indonesia

Indonesia can be divided into two provenances, namely:

(i) West Java Provenance

(ii) East Java Provenance

The West Java Provenance has a total rainfall of approximately 1,800 mm while the East Java Provenance has approximately 1,280 mm of total rainfall (Anon, 1966). Good growth and good timber quality may be demonstrated by these provenances as the rainfall range is within the limit where good teak forest occurs in Burma. These two Indonesian provenances, although possibly not natural, are of considerable interest. They are close to the equator and represent climatic conditions within the range of teak (see Pasuruan in Figure 7.2). These two provenances should be included in most studies and should be essential constituents in trials for areas of latitude of 10° or less. For example, these provenances should certainly be tested for Papua New Guinea.

10.2.6 Summary

The provenances listed above constitute a very broad division. When collecting seed for provenance trials, altitude and forest type within each region might also be considered.

Areas at latitudes greater than 16° should have the following provenances tested as a basic minimum:

India (i)a Northern evergreen provenance

(i)b Northern moist deciduous provenance

(i)c Northern dry deciduous provenance

Burma (i) Northern provenance

(ii) Southern provenance

(iii) Eastern provenance

(iv) Central provenance

(v) Tenasserim provenance

Thailand Thai provenance

Laos Laotian provenance

Similarly for areas of latitude less than 16°, the following provenances should be included.

India (ii)a Southern evergreen provenance

(ii)b Southern moist deciduous provenance

(ii)c Southern dry deciduous provenance

(ii)d South-eastern evergreen provenance

Indonesia (i) West Java provenance

(ii) East Java provenance

It is emphasized that these sub-divisions of provenances are tentative only. The major division based on the level of 16° latitude should not be regarded as necessarily exclusive and extensive modification to these proposals is likely as more detailed knowledge becomes available.

10.3 Selection at the individual tree level

In the absence of results from detailed provenance studies, careful selection of trees in the local region should be carried out to establish initial seed orchards.

Characteristics required for selection at the individual tree level have been discussed in detail in Chapter VIII, but are again outlined below for the completeness of this section. Desirable features of individual teak trees are:

(i) Late flowering

(ii) Superior height and diameter growth

(iii) Flat branches, slightly ascending and of small diameter

(iv) Branches on merchantable bole should be shed rapidly

(v) Crown should be comparatively narrow with a low ratio of crown diameter to stem diameter

(vi) Bole should be free of sweeps and kinks with no fluting and little buttressing

(vii) Bole should have little taper and have straight grain

(viii) Resistance to butt rotting fungi

(ix) The timber produced should be of superior quality in terms of strength and appearance

(x) The regular production of profuse large viable seed

Age at which selection is made is very important in the selection of plus trees. Selection in young stands can be misleading without a knowledge of the correlation between juvenile and adult plants (Kedharnath and Matthews, 1962). Determination of the age at which a measure of probable performance at maturity is desirable (Kedharnath, 1966). Reliable data is presently not available and practice varies considerably from country to country. In Trinidad, selection of teak plus trees is made from stands which are at least 20 years old (Chalmers, 1962). In Papua New Guinea, however, selections are made in stands of 8 - 10 years of age (Cameron, 1966). Cameron justified his selection from young stands with the fact that rapid and early development of teak in Papua New Guinea results in early expression of the undesirable characters, and thus less likelihood of wrong selection. In support of Cameron, Kedharnath and Matthews (1962) stated that because of the fast growth of teak, differences in height, stem diameter, internode length, number of leaves, the angle at which the leaves are carried on the stem can be observed even in the first year of its life. However, these authors also feel that any assessment of these characters should be carried out over several years to check a possible variation with age. Clearly, age at which plus trees could be selected still remains to be determined. For the present, it appears that teak trees over ten years of age could be selected for the characteristics required.

10.3.1 Testing of selected trees

Progeny tests may be established to determine hereditary differences between individual trees using either open-pollinated seeds (Kedharnath and Matthews, 1962; Wright, 1962; Cameron, 1966). Open-pollinated seeds are obtained from pollination effected by wind or insects, whilst control-pollinated seeds are obtained from an artificial transfer of pollen from one flower to another. Under the latter conditions both parents are known with certainty (Wright, 1962), but under the former only the seed bearing parent is known.

There are advantages and disadvantages in both types of pollination. Control-pollination is a more accurate way of getting a progeny with the required characteristics (Kedharnath and Matthews, 1962). It is essential for species or racial hybridization, and is desirable in selective breeding programmes (Wright, 1962). However, this pollination method involves considerable labour, numerous research staff, and consequently high expenditure (Wright, 1964).

Details of the techniques used for control-pollination of teak are discussed below. Wright (1962) has outlined the basic procedures necessary to effect control-pollination with such species as teak, which are monoecious, possibly self-compatible and insect pollinated. Trees have to be climbed to emasculate and bag flowers, and then later to effect the pollination. The processes of emasculation and pollination may be slow and consequently expensive. In teak, the time available for emasculation is very short (Bryndum and Hedegart, 1969). Detailed and complicated labelling of flowers is also necessary and seed collection, nursery procedures, field establishment and maintenance of control-pollinated progeny trials are expensive due to the large number of treatments which are usually included. Duffield and Snyder (1958) suggest as an approximate guide the labour involved is increased by a factor equal to the number of parent trees involved in control-pollination.

Only one parent tree is known in the seed obtained from open-pollination. However, the labour of pollination is not required, and the trials are much less complex than those containing seed produced by control-pollination. If well designed, open-pollinated trials can give reliable estimates of the general combining ability of the known parents (Wright, 1958). Although Wright noted that the rate of genetic gain in such a programme would usually be below the maximum, he also considered an improvement programme could be based entirely on the results of progeny tests of open-pollinated seed. Work involved with this type of pollination is less and large numbers of seeds can easily be obtained. Thus, it could be most suitable to apply initially for tree breeding programmes in Burma or other areas where funds and research staff are limited.

10.3.2 <u>Control-pollination of teak</u>

Techniques for the control-pollination of teak have been studied by Bryndum and Hedegart (1969) in Thailand. These authors found the teak flower opens a few hours after sunrise, pollination is completed the same day,and the corolla together with the anthers which are attached to it fall off in the evening or the next morning. If, however, no fertilization occurs, the whole flower including the pistil is shed. When the flower opens, the anthers are flat with no pollen visible.

Within one hour, the anthers swell, become fully inflated, and small quantities of pollen appear. By midday, thick belts of pollen are present. The authors concluded that when control pollination is required, isolation and emasculation must be carried out within one hour of the flowers becoming fully opened. Artificial pollination may be effected by rubbing a freshly cut anther gently against the stigma using a pair of tweezers. Alternatively, a small brush can be used to apply the pollen.

Bryndum and Hedegart also determined the optimum period for control-pollination by studies including crossings and selfings of 14 trees aged 7 - 30 years. The pollination process was carried out at four different periods during the day. Pollinations carried out between

(i) 8 a.m. and 9 a.m. gave 23 per cent fruit yield

(ii) 10 a.m. and 11 a.m. gave 42 per cent fruit yield

(iii) 12 noon and 3 p.m. gave 40 per cent fruit yield

(iv) 4 p.m. and 6 p.m. gave 16 per cent fruit yield

Thus, the optimum period of pollination appeared to be between 10 a.m. and 3 p.m.

The experiment also demonstrated that the species was primarily outbreeding, but that self-fertilization was possible. Cross-pollinated flowers gave a higher fruit yield (27 per cent) than did self-pollinated flowers (1 per cent). In addition, the seed from the cross-pollination gave better germination than that from the self-pollination, 90 per cent as against 13 per cent respectively.

The requirements for control-pollination of teak are therefore stringent. The number of flowers which could be emasculated by each worker would be very limited in the available time (approximately one hour daily). The cost of a large scale control-pollinated testing programme thus appears almost prohibitive.

10.4 Vegetative reproduction of teak

Vegetative reproduction has been commonly used to propagate teak trees for breeding purposes (Chalmers, 1962; Kedharnath and Matthews, 1962; Cameron, 1966; Hedegart, 1971). This may be done by budding, grafting, or cuttings. Budding is most generally used as it gives a high survival percentage, requires less attention and makes more economical use of scion material than other methods (Chalmers, 1962). Outlines for each method follow.

10.4.1 Budding

The method is based on a technique used extensively for budding of rubber trees (*Hevea brasiliensis* Muell. Arg.) known as 'forkert budding' (Keiding and Boonkird, 1960; Chalmers, 1962; Kedharnath and Matthews, 1962; Horne, 1966). The method has been described in detail for teak by Horne. Branches are collected from the upper or outer crowns of the plus trees and individual bud patches are cut from these branches by slicing off pieces of bark about five centimetres long. The bud is inserted about 0.3 metre above the ground on a one year old stock plant. Two vertical incisions forming a pointed arc about five centimetres long are made in the rind. The rind flap is lifted and a rectangular piece of bud from the selected tree is placed inside the exposed patch, with the cambium of the patch in contact with that of the stock plant. The rind flat is then pushed back into place and the union covered with a piece of palm leaf bound firmly round the bud patch. The patch is shaded, usually by loosely tying a large teak leaf over it. The binding is removed 10 - 14 days later, and the flap of rind cut off, exposing the bud patch. As soon as the bud starts to open the stock plant is cut off approximately 15 cm above the union. Usually buds commence sprouting four to eight days after exposure of the patch (Keiding, 1959; Kedharnath and Matthews, 1962).

Minor modifications to the practice are usual in Trinidad and Thailand. In Trinidad, 'shield budding' using a 'T' shaped incision is preferred (Chalmers, 1962). In Thailand, 'open-two-flap' budding is used (Hedegart, 1971). In this method, a piece of bark is removed, and two flaps are made one above and one below the area without bark. The bud from the selected tree is inserted between the two flaps followed by normal binding. Hedegart claimed the buds, especially the larger ones, are less damaged by this method than by the forkert budding method.

10.4.2 Grafting

Work on grafting technique was carried out in India by Rawat and Kedharnath (1968). Two to three year old root stocks were used and cleft grafts were made on the portion of the stems 1 - 3 cm in diameter. The scions were collected from the uppermost third of the selected trees. For grafting, each was cut to a wedge shape 5 - 6 cm in length whilst each root stock was tipped and had the stem cut vertically to a depth of

5 - 6 cm. The prepared scion was inserted into the cleft and the cambia of the stock aligned with that of the scion. The union was tied with jute threads with alkathene ribbons over the jute to seal the joint. The bindings were removed when a union was established, evident from the presence of new sprouts. This usually occurred from four to five weeks after grafting.

Rawat and Kedharnath (1968) determined the optimum season for grafting by comparing results from trials in the months of March, April, May and June at Dehra Dun, India (see Table 34). They found a clear advantage was gained by grafting at the beginning of the rainy season in April and May. However, the optimum time for grafting in other localities could be different and local studies would be necessary.

Table 34. Percentage of 'take' in cleft grafting at different months of the year as given by Rawat and Kedharnath (1968)

Months	1963 (%)	1964 (%)	1965 (%)	1966 (%)	Average for 4 years (%)
March	40	35	25	40	35
April	80	90	80	85	84
May	90	95	85	90	90
June	25	30	25	35	29

10.4.3 Cuttings

A procedure for striking cuttings of teak has been outlined by Chalmers (1962). Cuttings 23 - 30 cm long, with terminal buds, were collected from the crown of plus trees before flushing. The cuttings were generally kept in polythene bags after collection and set out in the field within 48 hours.

The time of collection of cuttings is an important factor in rooting success. In Trinidad, cuttings collected in mid-April gave 57 per cent success, those collected in mid-May gave 36 per cent success, while those collected in July were a complete failure (Chalmers, 1962).

10.5 Establishment of seed orchard

Large quantities of improved seed of outbreeding tree species are usually produced by means of seed orchards (Zobel et al., 1958; Hedegart, 1971). Usually in such orchards clones of selected trees are established in a pattern facilitating cross-pollination between them. In some cases, seedling rather than clonal orchards may be used (Zobel et al., 1958). However, seedling orchards would appear to be unsuitable for teak as late flowering is a highly desirable characteristic (see sections 5.1 and 8.2). Thus, clonal orchards should be preferred particularly as simple vegetative propagation is possible.

Kedharnath and Matthews (1962) considered seed orchards should have fertile soil, capable of growing good quality teak, and be at least four hectares in area. An area of approximately eight hectares was considered to be a better size as on these larger areas a larger quantity of pollen is produced. Management of larger blocks is also usually simpler. However, orchard size would also appear to be determined by seed yields and seed requirements which may vary for different locations in different countries. For example, a suitable size for teak seed orchards in Thailand is considered to be 25 hectares (Hedegart, 1971).

Kedharnath and Matthews (1962) specify a seed orchard site should be isolated from other teak stands by at least 400 metres. If there should be other seed orchards in the locality representing teak from different forest types, pollen barriers with a width of approximately 100 metres composed of unrelated species should be established. Kedharnath and Matthews considered between 30 - 60 clones should be incorporated in one seed orchard, so that each has an equal chance of being pollinated by all others. The arrangement should also allow a balanced mixture of clones to be retained after thinnings.

As trees in seed orchards are required only for seed production, wide initial spacing with the least number of thinnings is desirable. This is more economical, and probably promotes better crown development and seed yield. However, weed suppression and elimination of trees found to be genetically inferior should also be considered in determining initial spacing. Thus, Kedharnath and Matthews (1962) suggested an initial spacing of 4 m x 4 m, with two mechanical thinnings resulting in a final spacing of 16 m x 16 m. In Thailand, an initial spacing of 3 m x 3 m was found to be too dense and resulted in excessive thinnings (Hedegart, 1971).

10.6 Summary

The existence of variation in teak has been well established by the initial provenance trials carried out in various teak growing countries (see section 9.2). However, the established trials are insufficient in scope to enable recommendation concerning provenance selection to be made. The performance of various provenances in specific localities still remains to be determined and should have a high priority in any breeding programme. It may be possible to make more precise recommendations when the environmental factors influencing variation in the species are more fully understood. The experiment reported in Chapter XV was established to assist in this.

Individual tree variation of the local provenance can be exploited by tree breeding using clonal seed orchards. Seedling seed orchards would be unsuitable as late flowering is a desirable characteristic. Moreover, the species can be easily propagated vegetatively. Progeny testing by means of control-pollinated seed appears too involved and expensive. The use of open-pollinated seed is recommended for trials as it is cheaper and more easily available in quantity.

CHAPTER XI

THE NEED FOR EXPERIMENTAL STUDIES AND DETAILS OF THE EXPERIMENTS CONDUCTED

11.1 Importance of experimental studies

In a plantation establishment programme, particularly where the introduction of an exotic species is considered, it is important to have some knowledge of the variation patterns within the species concerned. An understanding of the response of the provenances to the major climatic factors is particularly important. This will facilitate a more precise selection of provenances for provenance trial or for planting.

In the review on variation in tree species in Chapter IX, widespread studies indicated the existence of variation in teak in volume production, timber qualities and survival. However, the trials were insufficient to permit the making of detailed recommendations concerning provenance selection. To establish details of the variation patterns within the species, extensive provenance trials should be established in as many areas as possible, and particularly in areas used, or considered to be used, for teak plantation. To assist the establishment of such trials, 16 provenances from the natural teak zone were proposed as a basic minimum for these studies. The division of the proposed provenances being based on latitude, rainfall and temperature.

Before provenance results are available, the plantation programme will generally be progressing. Information concerning the factors controlling development and variation in the species is therefore most desirable. Such information would help in the tentative provenance selection necessary to permit plantation establishment to proceed before detailed results are available.

From the wide distribution of the species (see Chapter IV), it is clear the species generally will tolerate a wide range of climatic conditions. This also suggests that variation exists within the species as climatic factors are often important natural selection forces, a suggestion supported by the results of the provenance trials to date (section 9.2). Climate exercises its influence on the response in tree species mainly through the agencies of temperature, light and water (Callaham, 1962; Treshow, 1970). Thus, in order to be able to give more precise prescription for selection of provenance for a particular area, understanding of the response of the species to temperature, light and water regimes is necessary. Detail of the rainfall and temperature regimes within which teak occurs naturally have been recorded (see Chapter IV), but information on the response of the species to temperature, photoperiod and water is so far not available.

11.2 Experiments conducted and facilities used

11.2.1 General

As controlled environment facilities were available in Canberra it was possible to make preliminary studies to determine the importance of temperature and daylength to the development of teak. Three separate experiments were conducted, namely:

(i) the effect of low temperature regimes on teak seedlings

(ii) the effect of photoperiod and night temperature on teak seedlings

(iii) the effect of day and night temperatures on the development of five provenances of teak seedlings.

The experiment carried out in Thailand by Hedegart (see section 9.2) and experience in Burma (see section 5.3), suggest that viability of teak seed varies with provenance. Germination of seeds of the five provenances studied was therefore also compared in a separate experiment, using the method of assessing germination detailed in sub-section 5.4.3.

11.2.2 Facilities used

The seedlings were germinated and grown in naturally lit glasshouses of C.S.I.R.O. phytotron maintained at constant temperature regimes. The day temperatures available in these glasshouses range from 15°C to 36°C, and night temperatures from 10°C to 31°C. The day temperatures are held from 8.30 a.m. to 4.30 p.m., and night temperatures for the remaining 16 hours. Each glasshouse has a night temperature 5°C below the respective day temperature. Different day and night temperature combinations can be obtained by moving plants on trolleys between glasshouses with the required temperatures at 8.30 a.m. and 4.30 p.m. daily. The natural daylength in all glasshouses is extended to 16 hours by means of low intensity incandescent lamps which provide illumination of 25 fc. at plant height (4.00 a.m. to 8.00 p.m.) throughout the year, and the relative humidity is kept above 40 per cent in all glasshouses (Anon, 1970b).

Photoperiodic experiments were conducted in B-cabinets (Morse and Evans, 1962; Anon, 1970b). These cabinets are also naturally illuminated, but the period of illumination can be limited by automatic shutters, and extension of photoperiod is provided for by incandescent lamps giving intensity of 25 fc. at plant height. The B-cabinets used were open to natural daylight from 8.30 a.m. to 4.30 p.m. with the supplementary light used for the required additional photoperiod. To maintain consistency, the temperature regimes applied followed those usual in the open glasshouse with day temperature maintained from 8.30 a.m. to 4.30 p.m., and night temperature for the remaining 16 hours.

Throughout all experiments watering was done with modified Hoagland solution (see Appendix III) at 8.30 a.m. and with tap water at 12 noon, and 3.30 p.m. daily.

11.3 Assessment procedures

11.3.1 General

Plant heights were measured from cotyledon level to the point where the last pair of leaves split. The cotyledons were normally situated below the first leaf pair and approximately one half-centimetre above the level of growth medium mixture. Slide vernier calipers were used for diameter measurements, taken at the mid-point between the first and the second pair of leaves in a direction parallel to the second pair of leaves.

Leaf areas were measured with an airflow planimeter as described by Jenkins (1959) (Figure 11). This basically

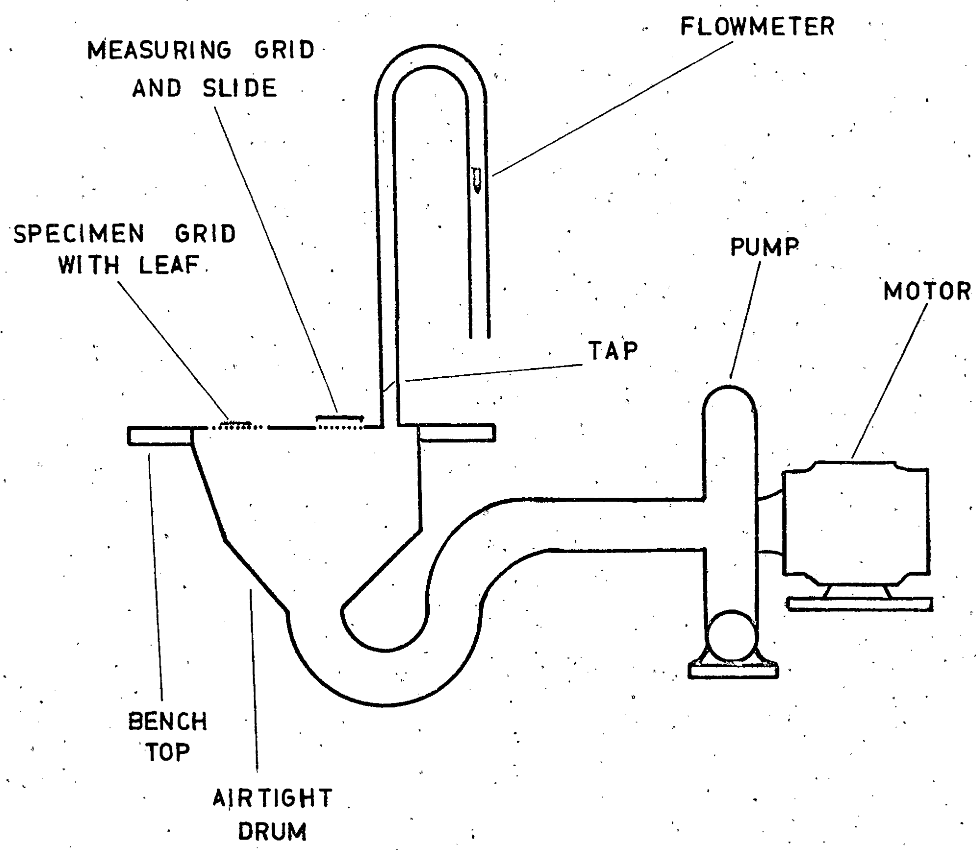


Figure 11 Diagram showing the working principle of an airflow planimeter.

consists of identically perforated plates mounted in the top of an airtight drum, which is connected to a constant speed rotary pump. One plate (specimen grid) is uncovered, while the other (measuring grid) is covered by an air-tight slide. The pressure within the drum, which is shown on the flowmeter is noted before any leaf is mounted. Leaves are then mounted on the specimen plate and are held flat by suction pressure. The pressure in the drum is readjusted back to the original by movement of the slide covering the measuring grid. At this point the area of the leaves is equal to the area of the exposed portion of the measuring grid. This area is recorded by a vernier scale mounted on the slide.

In order to determine the dry weights of leaves, stems, and roots separately, the roots were cut from the stem at the junction of the highest root and the main stem. Stem and leaves (including petioles) were also separated. All portions were dried in an oven maintained at 80°C for 10 days. Dried material was allowed to cool and stabilize to room saturation point for at least half an hour before weighing. Leaves, stems and roots were then weighed separately.

11.3.2 Assessment of growth

(a) Overall growth and dry matter production.

Growth of mature trees in the field is generally compared by direct measurements of height and diameter, as it is difficult to carry out detailed physiological measurements on large trees. Moreover, useful differences between mature trees are normally sufficiently large to be adequately demonstrated.

In seedlings, however, the differences in growth between treatments may be relatively small, thus making it difficult to demonstrate the effect of the treatments by direct measurements (Eldridge, 1969). Moreover, the size of the seedlings at the time of measurement may well depend upon the size of the seedlings at the start of an experiment (Sweet and Wareing, 1968; Eldridge, 1969). Seedling studies assessed by direct measurement thus require seedlings, ideally, to be initially identical in size and this may be impracticable, especially in species like teak with sporadic germination. Thus, in assessing growth of seedlings, methods in which initial size does not affect the final comparison are normally used.

Duncan and Hesketh (1968), considered leaf growth to be the best indicator of a plant's growth and they developed a method of comparing relative leaf growth where initial size of the seedlings need not be considered at all. However, the author found the large size and the very fast growth of teak leaves made this method difficult to apply. Moreover, this method gives only the comparison of the net photosynthesizing area, and internal factors of growth, such as rate of photosynthesis, were not considered.

The more usual method for assessing growth is to use the classical growth analysis procedures (Fisher, 1920; Williams, 1946). In these, plant growth at any time is considered to be a function of the size of the plant. The formula for calculation of the relative growth rate (RGR) over a period of time is:

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

where, RGR is the relative growth rate of the dry weight of the whole plant, t is the time of harvests, W_1 is the total dry weight of the whole plant at time t_1, and W_2 is the total dry weight of the whole plant at time t_2. For fuller discussion of the formula, see Williams (1946).

Relative growth may also be estimated using this formula for leaf area, plant height, and plant diameter (Eldridge, 1969).

Growth is considered to be directly related to the two factors (i) photosynthetic area and (ii) rate of photosynthate production per area of photosynthetic tissue.

(i) Photosynthetic area is measured by the leaf area ratio: $LAR = \frac{L}{W}$

where, LAR is the leaf area ratio, L is the total leaf area, and W is the total dry weight of the whole plant.

(ii) The rate of photosynthate production is determined from the relative growth rate and leaf area ratio according to the relationship

$$RGR = LAR \times NAR,$$

where, NAR is the net assimilation rate or the rate of photosynthate production per area of photosynthetic tissue.

The formula most commonly used to determine net assimilation rate follows from those used for RGR and LAR. It is:

$$NAR = \frac{W_2 - W_1}{L_2 - L_1} \times \frac{\log_e L_2 - \log_e L_1}{t_2 - t_1}$$

where, t is the time of sampling, W_1 is the total dry weight of the whole plant at time t_1, W_2 is the total dry weight of the whole plant at time t_2, L_1 is the total leaf area at time t_1, and L_2 is the total leaf area at time t_2. This formula for NAR makes the assumption that the relationship between W and L remains constant over the period t_1 to t_2.

In the experiments comparing teak seedling performance in growth, and in particular in dry matter production, both direct and indirect measures were used. Measurements were made of total dry weight, total leaf area, diameter increment, relative diameter growth, height increment, relative height growth, RGR, NAR, and LAR.

(b) Dry matter distribution

The proportion of photosynthate distributed to various parts of a plant has long been considered as important and the shoot/root dry weight ratio has frequently been cited as an important measure. This is because the development of a plant is critically controlled by the balance between the shoot and root development (Kramer, 1958; Kramer and Kozlowski, 1960; Kozlowski, 1962, 1971; Ledig and Perry, 1965). Stress by any individual environmental factor normally results in a change of shoot/root ration. Many investigators have used this ratio to determine the effect of environmental factors on the distribution of photosynthate towards the shoot and root (Ledig and Perry, 1965; Ledig, *et al.*, 1970). However, Ledig and Perry (1965) and Ledig, *et al.*, (1970) note that shoot/root ratio changes with size of the plants, and suggest the use of allometric formula to determine distribution patterns. The general allometric formula is

$$Y = aX^k, \text{ or}$$

$$\log_e Y = a + k \log_e X$$

where, X is the dry weight of one plant organ, Y is the dry weight of another, and 'a' and 'k' are constants. These relationships can be used to make comparison between portions of the plant,e.g. shoot:root or between one organ and the total plant.

In assessing treatments, the simplest way is to establish the linear regression between logY and logX. If treatments differ in their effects on the balance in weight of the plant organs, the slope 'k' of the allometric regressions will differ. This relationship was used whenever possible in the studies of dry matter distribution in this thesis. However, where the number of samples in treatments was small, or where the regressions could not be compared due to the data obtained failing to satisfy the tests for homogeneity of regression coefficients (Steel and Torrie 1960), the simple ratio of $\frac{\log Y}{\log X}$ was used to study the effect of treatments on dry matter distribution.

Consequently, the distribution of photosynthate to the various parts of teak seedlings for each treatment was studied. The relationship between total weight and

(i) leaf weight

(ii) stem weight

(iii) root weight

were all determined by allometric procedure. As shoot/root ratio was frequently referred to in physiological literatures, the relationship between shoot and root were also determined allometrically for completeness.

11.3.3 Statistical analysis

The normal analysis of variance procedure was carried out for all experiments (Steel and Torrie, 1960; Freese, 1967). When significant results were obtained, treatment means were compared using the least significant difference method (Steel and Torrie, 1960). This procedure is simpler to apply than the more accurate Duncan's Multiple Range Test (Steel and Torrie, 1960), and the differences between the results of these two tests over the number of treatments compared in these experiments was minimal.

possible. One plant from each group was randomly selected for each temperature treatment. Thus, there were a total of five seedlings in each temperature regime.

The plants were measured on the 15th day and on either the 41st or 42nd day after treatment commenced. Plants under treatment 15°/10°C were in extremely poor condition after 15 days and were not measured as it was considered the treatment would have to be discarded. However, the seedlings under this regime did survive to the end of the experiment, allowing measurements on the 42nd day.

At measurement on the 15th day, leaf length, leaf breadth, and seedling height were recorded non-destructively, and at the final measurement and harvest, leaf length and breadth, height, dry weights of leaf, stem and root were recorded.

Previous preliminary studies indicated a very high correlation between leaf dimension (length x breadth) and leaf area ($r = 0.999$). Based on this study, the leaf areas from two plants from each treatment were measured by means of an airflow planimeter. These measurements were used to establish a relationship between leaf dimension and leaf area for each treatment, and these relationships were then employed to determine the leaf area of the remaining plants. The relationships for each treatment were as given below:

Treatment	Relationship (regression)	Correlation coeff.
27°/22°C	$y = 32.3 + 1.7x$	0.998
21°/16°C	$y = 7.2 + 1.8x$	0.997
18°/13°C	$y = 3.0 + 1.8x$	0.994

The relationship for treatment 15°/10°C was not determined, but the leaf area for this treatment was calculated using the relationship for 18°/13°C treatment.

The effects of differing temperature regimes on the development of teak seedlings were compared on the basis of (a) overall growth and dry matter production and, (b) distribution of dry matter.

In the assessment of growth, the effects of the various treatments on dry matter production, total plant weight, height, leaf area, and leaf area ratio (LAR) were examined. Leaf area ratio is not strictly a measure of growth or of dry matter production. However, it is frequently associated with relative growth rate in the calculation of net assimilation rate, and both these are measures of growth or growth potential. Thus, for simplicity, leaf area ratio is included in this section.

In order to check comparisons of heights and leaf areas under the different treatments applied, the relative height growth and the relative leaf growth were also calculated and used for comparisons. A measure of the relative increase in dry weight would also have been desirable, but could not be included as only one measurement of the feature was available.

Leaf area ratio was calculated using the formula - $LAR = \frac{L_A}{W}$, where L_A = leaf area, and W = total dry weight, and relative height growth and relative leaf growth were calculated using the formula -

$$RGR_{h \text{ or } L} = \frac{\log_e X_2 - \log_e X_1}{t_2 - t_1}, \text{ where}$$

X_n = either height or leaf area recorded at harvest n, and t_n = time of harvest. These formulae were discussed in more detail in Chapter XI.

Allometric formula $\log_e(y) = a + k \log_e(x)$, where x and y are the dry weights of the particular parts of the plant, and a and k are constants, was used for the assessment of dry matter distribution. This was also discussed under Chapter XI. Significant regressions were calculated for each treatment but valid comparisons between these could not be made as they did not satisfy the homogeneity of regression coefficient test (Steel and Torrie, 1960, p. 319). This was due to the presence of occasional anomalous results. These would be unimportant if a large number of samples were present, but with so few samples they regularly distorted the regression data. The calculation of the relative growth of the various parts of a plant by the allometric formula was therefore to be replaced by the simpler expression $\frac{\log_e x}{\log_e y} = m$, where x and y are the respective dry weights of the particular portions (e.g. shoot and root) of each plant. Values for individual plants were calculated and standard techniques for analysis of variance applied. Where significant, the individual values for each treatment were compared using the L.S.D. test at five per cent significant level.

12.3 Results

The results are summarized in Tables 35 and 37 and Figures 12 and 14, with details of the analyses in Tables 36 and 38.

Table 35. Mean results for overall growth and dry matter production of five seedlings at the temperatures indicated after 27 days

Treatment	Dry wt. (g)	Height (cm)	Relative height growth (cm/cm/day)	Leaf area (cm^2)	Relative leaf growth ($cm^2/cm^2/day$)	Leaf area ratio (cm^2/g)
27°/22°C	46.84	49.9	0.0564	6395.8	0.0584	140.06
21°/16°C	15.14	10.6	0.0238	1231.4	0.0280	83.02
18°/13°C	9.42	6.6	0.0115	670.0	0.0147	71.94
15°/10°C	3.38	4.7		355.8		107.02
L.S.D.	6.89	3.8	0.0065	658.97	0.0065	21.16

Table 36 Analysis of variance for low temperature regimes experiment. Overall growth and dry matter production.

Source of variation	df.	Sum of squares	Mean squares	F
Dry weight				
Temperature	3	5626.77	1875.59	74.96**
Grade	4	420.68	105.17	4.20*
Error	12	300.18	25.02	
Height				
Temperature	2	0.00538	0.00269	134.5**
Grade	4	0.00008	0.00002	1.0
Error	8	0.00016	0.00002	
Relative height growth				
Temperature	2	0.00538	0.00269	134.5**
Grade	4	0.00008	0.00002	1.0
Error	8	0.00016	0.00002	
Leaf area				
Temperature	3	121397475	40465825	176.97**
Grade	4	2527953	631988	2.76
Error	12	2743906	228659	
Relative leaf growth				
Temperature	2	0.00502	0.00251	125.5**
Grade	4	0.00013	0.00003	1.5
Error	8	0.00013	0.00002	
Leaf area ratio				
Temperature	3	13643.64	4547.88	19.29**
Grade	4	945.22	236.31	1.00
Error	12	2829.42	235.79	

Figure 12.1 The response of teak seedlings in (a) dry weight (b) height (c) relative height growth and (d) relative leaf growth to the low temperature regimes studied.

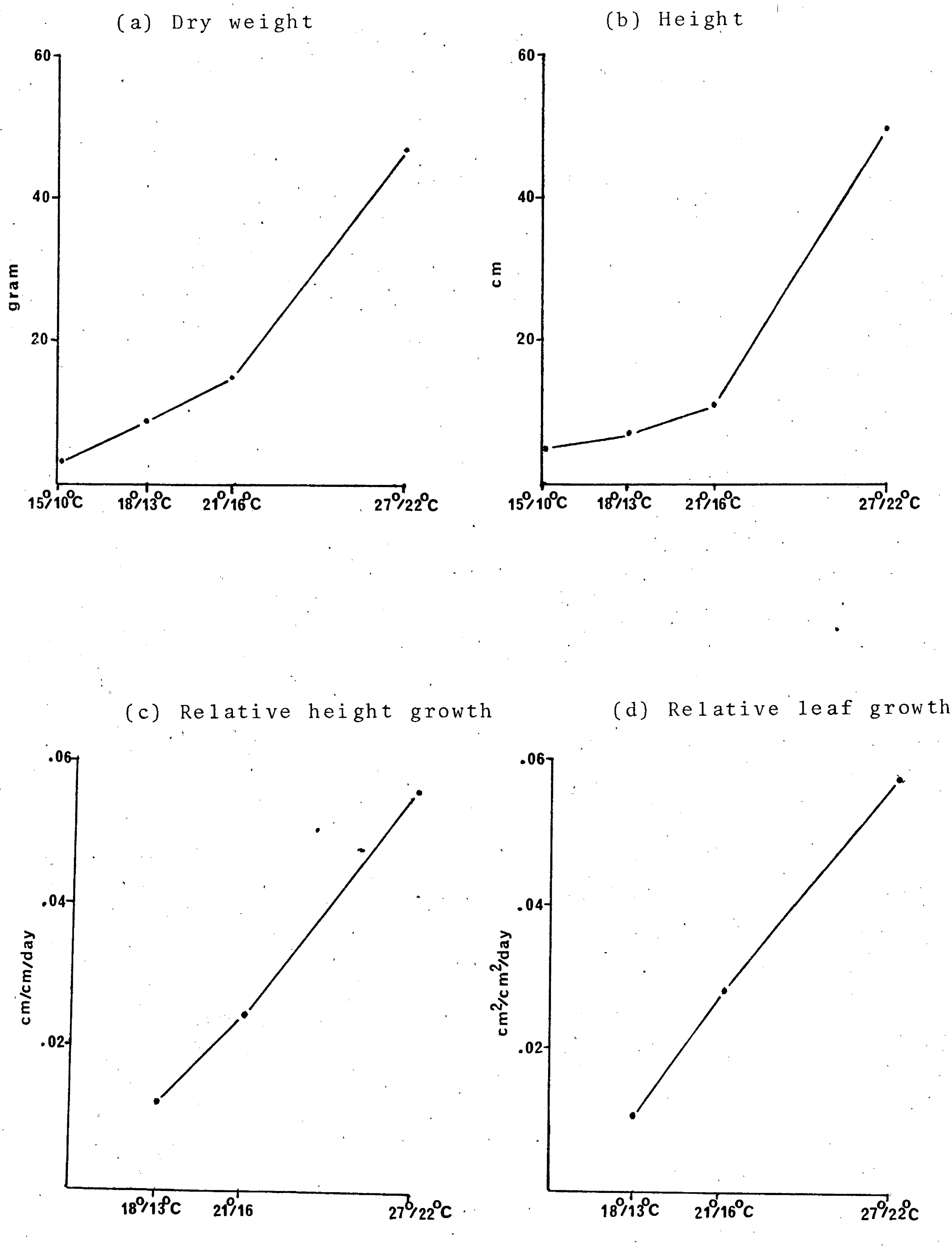
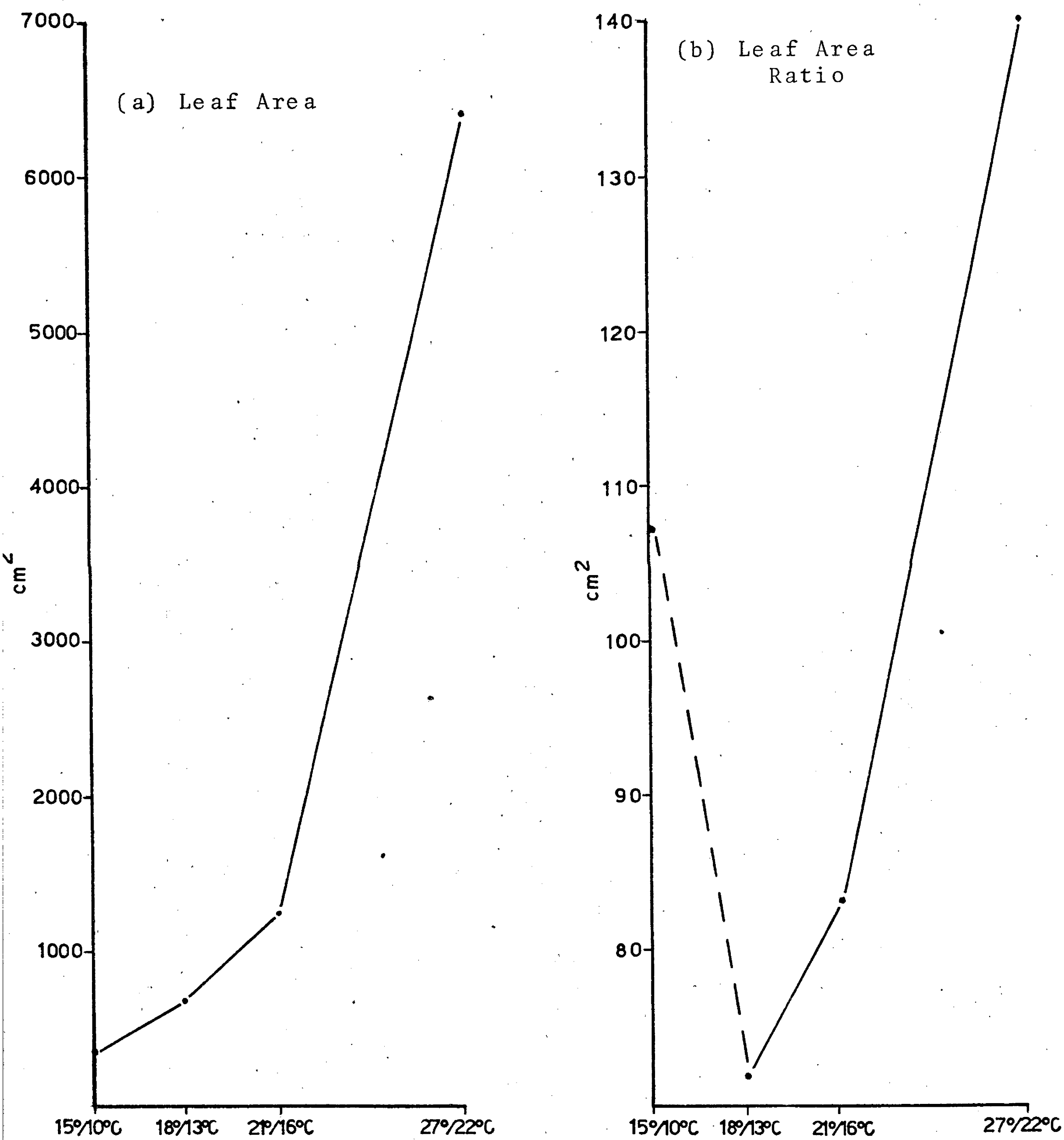


Figure 12.2 The response of teak seedlings in (a) leaf area, and (b) leaf area ratio to the low temperature regimes studied.



12.3.1 Overall growth and dry matter production

Dry weight. Total dry weight increased at the higher temperatures. The total dry weight of teak seedlings at 27°/22°C (46.8g) was significantly greater than at 21°/16°C (15.1g) and similarly the weight at 21°/16°C was greater than at 18°/13°C (9.4g) and at 15°/10°C (3.4g). However, the differences between the figures for 21°/16°C, and for 18°/13°C and 15°/10°C were significant only at 10 per cent level. But as the difference between 21°/16°C and 15°/10°C was significant at one per cent level, there was a very clear trend to an increase in the rate of production of dry matter with temperature (Figure 12.1a).

Height. Seedling height increased with temperature (Figure 12.1b). The height of teak seedlings at 27°/22°C (49.9cm) was significantly greater than the height at 21°/16°C (10.6cm), whilst the height at 21°/16°C was significantly greater than at 18°/13°C (6.6 cm). There was however no significant difference in height at 18°/13°C and at 15°/10°C (4.7 cm). Thus teak seedlings increased in height significantly as the temperature was increased from 18°/13°C to 27°/22°C, but the increase from 15°/10°C to 18°/13°C was not significant.

Relative height growth. The relative height growth measurements gave similar results to the raw height growth data (Figure 12.1c). The relative height growth at 27°/22°C (0.0564cm/cm/day) was significantly greater than at 21°/16°C (0.0238cm/cm/day), and the relative height growth at 21°/16°C was significantly greater than at 18°/13°C (0.0115cm/cm/day). The relative height growth at 15°/10°C was not calculated as only one measurement was available.

Leaf area. Leaf area increased with temperature (Figure 12.2a). The leaf area at 27°/22°C ($6395.8cm^2$) was significantly greater than at 21°/16°C ($1231.4cm^2$), whilst the leaf area at 21°/16°C tended to be greater than at 18°/13°C ($670.0cm^2$) (significant at 10% level). The difference between the leaf area at 18°/13°C and 15°/10°C ($355.8cm^2$) was not significant. As the values obtained at 21°/16°C and 15°/10°C differed significantly, there was again a clear trend for an increase of leaf area with temperature.

Relative leaf growth. The relative leaf growth increased with the increase in temperature (Figure 12.1d). The relative leaf growth at 27°/22°C ($0.0584cm^2/cm^2$/day) was significantly greater than at 21°/16°C ($0.0280cm^2/cm^2$/day), whilst the relative leaf growth at 21°/16°C was significantly greater than at 18°/13°C ($0.0147cm^2/cm^2$/day). Relative leaf growth at 15°/10°C was not calculated as only one measurement was available. Thus the relative leaf growth result vindicated the raw data figures.

Leaf area ratio. The leaf area ratio increased with temperature (Figure 12.2b). The leaf area ratio at 27°/22°C (140.06cm/g) was significantly greater than at 21°/16°C ($83.02cm^2/g$), but the difference between the leaf area ratios at 21°/16°C and at 18°/13°C ($71.94cm^2/g$) was not significant. Surprisingly, the leaf area ratio at 15°/10°C ($107.02cm^2/g$) was significantly greater than at both 21°/16°C and 18°/13°C. This was probably due to rather abnormal growth of the seedlings at 15°/10°C.

Figure 13 The effect of low temperature regimes studied on the growth and development of potted teak seedlings grown in the phytotron.

The seedlings appeared sickly and the leaves were yellowish in colour throughout the experimental period (Figure 13). Moreover, the small leaf area of the seedlings at this particular temperature (Table 35) indicated the high value recorded for leaf area ratio was due to the very small amount of dry matter present rather than to a relatively large photosynthesizing area.

12.3.2 Distribution of dry matter

The results obtained using the logarithmic ratios follow a similar trend to those results obtained by regression technique (allometric formula). The results for the temperature regime 15°/10°C were not calculated, due to the abnormal appearance, and the fact the correlation coefficients obtained by regression analyses were not significant.

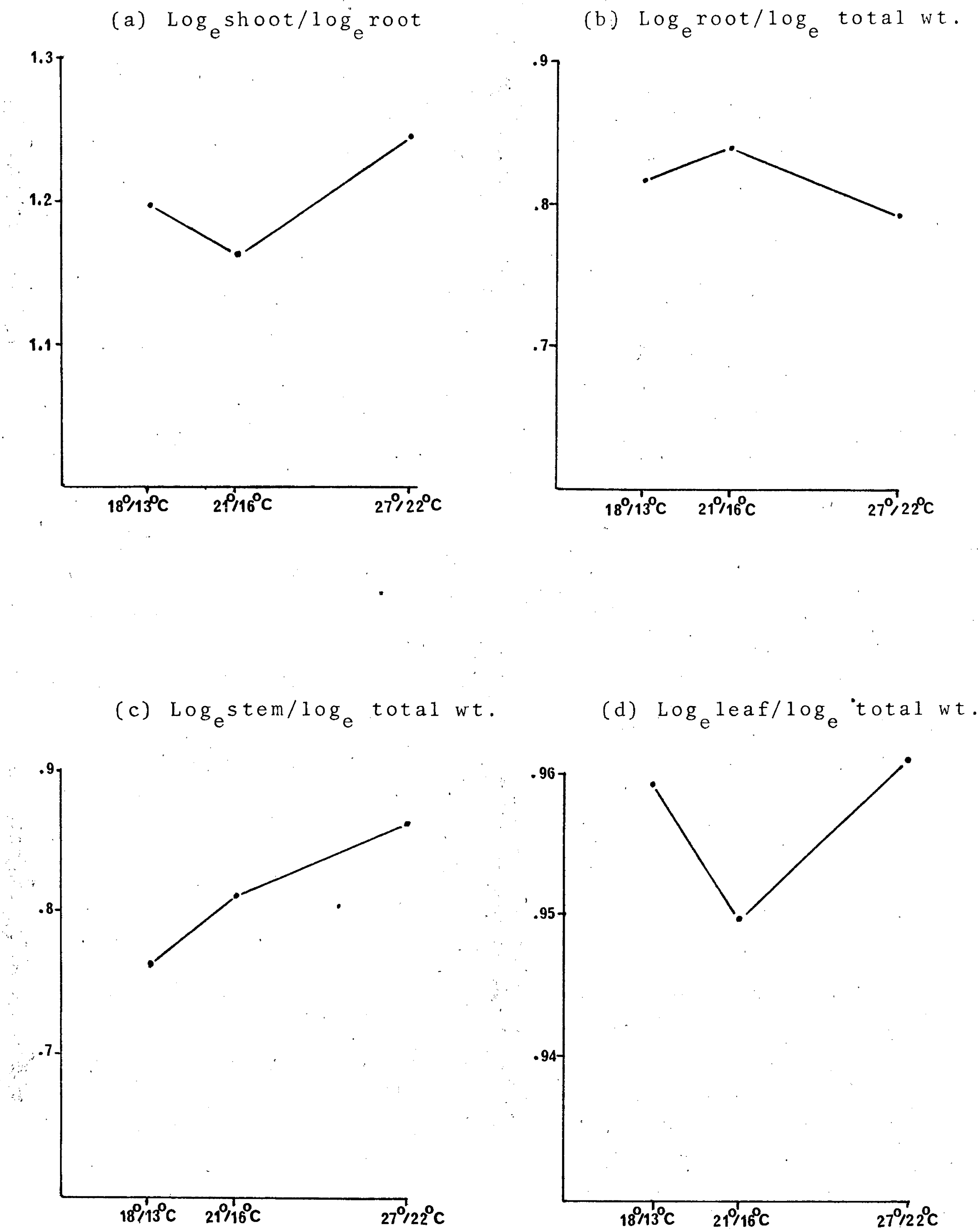
Relative growth of shoot to root. The relative growth of shoot to root was highest at 27°/22°C (1.25) followed in order of magnitude by 18°/13°C (1.20) and 21°/16°C (1.16) with the differences significant. Thus more photosynthate was distributed towards the shoot than the root at 27°/22°C than at 18°/13°C with the proportion of the photosynthate distributed towards the shoot least at 21°/16°C (Figure 14a).

Relative growth of root to the total plant weight. The relative growth of root weight to the total plant weight was highest at 21°/16°C (0.84) and followed in order of magnitude by that at 18°/13°C (0.82) and at 27°/22°C (0.79). The differences were significant. Thus more photosynthate was distributed towards the root at 21°/16°C, followed in order of magnitude by 18°/13°C and 27°/22°C. (Figure 14b).

Table 37 Summary of results for dry matter distribution

Treatment	$\frac{\log_e \text{shoot Wt}}{\log_e \text{root Wt}}$	$\frac{\log_e \text{root wt}}{\log_e \text{total wt}}$	$\frac{\log_e \text{stem wt}}{\log_e \text{total wt}}$	$\frac{\log_e \text{leaf wt}}{\log_e \text{total wt}}$
27°/22°C	1.2454	0.7943	0.8632	0.9609
21°/16°C	1.1610	0.8395	0.8105	0.9498
18°/13°C	1.1962	0.8166	0.7632	0.9592
L.S.D.	0.0341	0.0197	0.0171	0.0046

Figure 14 The effect of the low temperature regimes studied on the distribution of dry matter in teak seedlings.



Relative growth of stem to total plant weight. The relative growth of stem weight to the total plant weight increased with temperature (Figure 14c). The relative growth in stem was significantly greater at 27°/22°C (0.86) than at 21°/16°C (0.81), and in turn the relative growth at 21°/16°C was significantly greater than at 18°/13°C (0.76). Thus, the distribution of photosynthate towards the stem increased with the temperature from 18°/13°C to 27°/22°C.

Relative growth of leaf to total plant weight. The relative growth of leaf weight to total plant weight was significantly lower at 21°/16°C (0.95) than the other temperatures, whilst the difference at 27°/22°C (0.96) and 18°/13°C (0.96) did not differ significantly. Thus more photosynthate was distributed towards the leaf at 27°/22°C and 18°/13°C than at 21°/16°C (Figure 14d).

12.4 Discussion and conclusion

Clearly, the effect of low temperature regimes on growth of teak seedlings was very marked. There was a very strong trend for an increase in the total dry weight, height growth, and leaf area with increasing temperature from 15°/10°C to 27°/22°C. Generally, the increase was faster between 21°/16°C and 27°/22°C (see Figure 12.1 and 12.2).

The pattern of the distribution of dry matter was interesting (Figure 14). As mentioned above, the total dry weight decreased with the decrease in temperature from 27°/22°C to 15°/10°C. The distribution of photosynthate towards the stem followed the same trend. However, the distribution of photosynthate towards the shoot in relation to the root decrease from 27°/22°C to 21°/16°C, and increased again as the temperature was further decreased to 18°/13°C (Figure 14a). The distribution of photosynthate towards the leaf in relation to total weight followed the same pattern, whilst that of the root to total dry weight was just the reverse.(Figure 14b,d). Clearly, at 21°/16°C, the proportion of photosynthate distributed towards the roots increased whilst that sent towards the leaf was greatly reduced. 21°/16°C appears therefore to be a critical temperature, at which the seedlings probably started readjusting their physiological processes to adapt to lower temperatures. This requires more detailed study.

The possible critical low temperature at which a marked change in physiological process occurs was determined only for the glasshouse experiment. The corresponding field temperatures are of course not known, but considerable caution will be needed if teak is considered for areas where ambient temperatures regularly fall to 21°C by day and 16°C by night.

CHAPTER XIII

EXPERIMENT TO STUDY THE EFFECT OF PHOTOPERIOD AND NIGHT TEMPERATURE ON THE DEVELOPMENT OF TEAK SEEDLINGS

13.1 Object

To study the effect of photoperiod and night temperature on teak seedlings.

13.2 Materials and methods

Seedlings of Pati, Indonesian origin, obtained from the germination experiment as described under section 15.2 were used. Development of these seedlings was compared under six treatments provided by two temperature regimes of 33/22°C and 33/28°C (day/night) and three daylength regimes of 8, 12, and 16 hours at the C.S.I.R.O. phytotron. In all cases, the seedlings were illuminated by natural daylight for eight hours with any necessary additional daylight supplied by low intensity incandescent lamps. Twelve hours approximates to the average daylength of the natural teak zone, and 8 to 16 hours photoperiods were used to study the effect of shortening and lengthening of daylength from normal.

Approximately one week after germination, the seedlings had the first pair of leaves well developed, with each leaf approximately 3 cm long. At this stage, all seedlings were graded by size into 30 batches with three seedlings of equal size in each batch. Seedlings within each group were potted respectively into plastic pots of 10 cm, 15 cm, and 18 cm top diameters, using a 1:1 mixture of perlite and vermiculite as the potting medium. Five batches of seedlings (a total of 15 plants) were allocated to each treatment in a manner which distributed the variation evenly between treatments.

The seedlings were established in C-cabinets (Morse and Evans, 1962) in the C.S.I.R.O. phytotron and watered with nutrient solution and water according to the normal practice in the C.S.I.R.O. phytotron.

Seedlings within each group were harvested on the 14th, 23rd, and either the 36th or 37th days from the start of the treatment. At each harvest leaf area and dry weights of leaves, stem and roots were determined as described in section 11.3.1.

Measurements of height and diameter were made only on the seedlings in the large pots (18 cm top diameter) retained until the end of the treatment. The first measurements were taken on the 24th day, and the second measurements on the 36th or 37th days from the start of the treatment.

Relative growth rate, net assimilation rate and leaf area were determined for the period 14th to 23rd (period one) and 23rd to 37th day (period two) from the start of the treatment.

The assessment of the results was divided into two sections, (i) overall growth and dry matter production and (ii) dry matter distribution.

Overall growth and dry matter production covered the results recorded for relative growth rate (RGR), net assimilation rate (NAR), leaf area ratio (LAR), diameter growth and height growth.

The seedlings were too small to be measured for height and diameter at the commencement of the experiment. These values were therefore determined over the period specified above towards the end of the experiment. At the commencement of this period, the seedlings were of varying sizes. As large sized seedlings might have exhibited greater increments, relative increments using a log transformation were compared as well as straight raw data comparisons.

For assessment of dry matter distribution, logarithmic ratios of different parts of the plants were calculated for each individual plant.

These results were analyzed using a standard analysis of variance technique. Individual treatments were compared by means of an LSD test (Steel and Torrie, 1960) at the five per cent significant level.

13.3 Results

13.3.1 Overall growth and dry matter production

The results were as detailed in Tables 40 and 42 and Figures 15, 16 and 17, and the analysis of variance in Appendix IV.

Relative growth rate. The RGR was unaffected by both the photoperiod and the temperature regimes applied over both periods of study.

Over period 1, mean values for RGR under all six treatments varied only slightly and were within the range 121 - 142 g/g/day. The statistical analysis did reveal a significant (5% level) interaction between grade and daylength, but close examination of the results however showed this to be due to one unusually small plant in the 33/28°C and 12 hours photoperiod treatment. Thus the effect was considered to be due to chance and ignored.

Table 40 Results of photoperiod experiment on dry matter production.

Characteristic assessed	Temperature	Photoperiod (hours)			Mean
		8	12	16	
Relative growth rate (1) (g/g/day)	33°/22°C	0.140	0.136	0.134	0.137
	33°/28°C	0.142	0.121	0.134	0.132
	Mean	0.141	0.129	0.134	
Relative growth rate (2) (g/g/day)	33°/22°C	0.140	0.100	0.111	0.105
	33°/28°C	0.111	0.133	0.104	0.112
	Mean	0.108	0.117	0.108	
NAR (1) ($mg/cm^2/day$)	33°/22°C	0.592	0.661	0.685	0.646
	33°/28°C	0.511	0.511	0.579	0.534
	Mean	0.552	0.586	0.632	
NAR (2) ($mg/cm^2/day$)	33°/22°C	0.433	0.495	0.599	0.509
	33°/28°C	0.391	0.587	0.469	0.482
	Mean	0.412	0.541	0.534	
LAR (1) (cm^2/g)	33°/22°C	232.286	185.907	184.227	200.807
	33°/28°C	275.486	227.812	209.142	237.480
	Mean	253.886	206.859	196.685	
LAR (2) (cm^2/g)	33°/22°C	241.302	213.406	185.357	213.355
	33°/28°C	288.092	225.984	232.424	248.833
	Mean	264.697	219.695	208.890	
Dia. increment (cm/day)	33°/22°C	0.015	0.017	0.018	0.017
	33°/28°C	0.017	0.019	0.019	0.018
	Mean	0.016	0.018	0.019	
Relative Dia. growth (cm/cm/day)	33°/22°C	0.032	0.040	0.037	0.036
	33°/28°C	0.035	0.038	0.038	0.037
	Mean	0.034	0.039	0.038	
Height increment (cm/day)	33°/22°C	0.405	0.553	0.575	0.514
	33°/28°C	0.503	0.888	0.803	0.731
	Mean	0.454	0.721	0.689	
Relative height growth (cm/cm/day)	33°/22°C	0.059	0.058	0.058	0.059
	33°/28°C	0.056	0.061	0.061	0.059
	Mean	0.058	0.060	0.060	

Table 41.1 Statistical analysis for dry matter production

Source of variation	df.	Mean squares					
		RGR(1)	RGR(2)	NAR(1)	NAR(2)	LAR(1)	LAR(2)
Temperature	1	0.000159	0.000941	0.094304*	0.005495	10087.06**	9440.36**
Photoperiod	2	0.000405	0.000262	0.016399	0.052669*	9311.64**	8760.51**
Grade	4	0.001086	0.000122	0.019711	0.004959	16.90	56.78
Photo x Temp.	2	0.000234	0.001004	0.003108	0.031066	260.28	983.35
Grade x Temp.	4	0.000731	0.000576	0.023376	0.008910	104.73	105.85
Grade x Photo.	8	0.001912*	0.000802	0.037002	0.015762	151.91	129.26
Error	8	0.000500	0.000502	0.012896	0.008511	116.17	337.46

Table 41.2 Statistical analysis for diameter and height growth

Source of variation	df.	Mean squares			
		Dia. increment	Rel. dia. growth	Height increment	Rel. height growth
Temperature	1	0.000018	0.000002	0.3645**	0.000009
Photoperiod	2	0.000011	0.000084	0.2122**	0.000015
Grade	4	0.000012	0.000035	0.0253	0.000145*
Photo x Temp.	2	0.000002	0.000013	0.0352	0.000028
Grade x Temp.	4	0.000008	0.000040	0.0195	0.000031
Grade x Photo.	8	0.000008	0.000016	0.0177	0.000052
Error	8	0.000004	0.000027	0.0143	0.000024

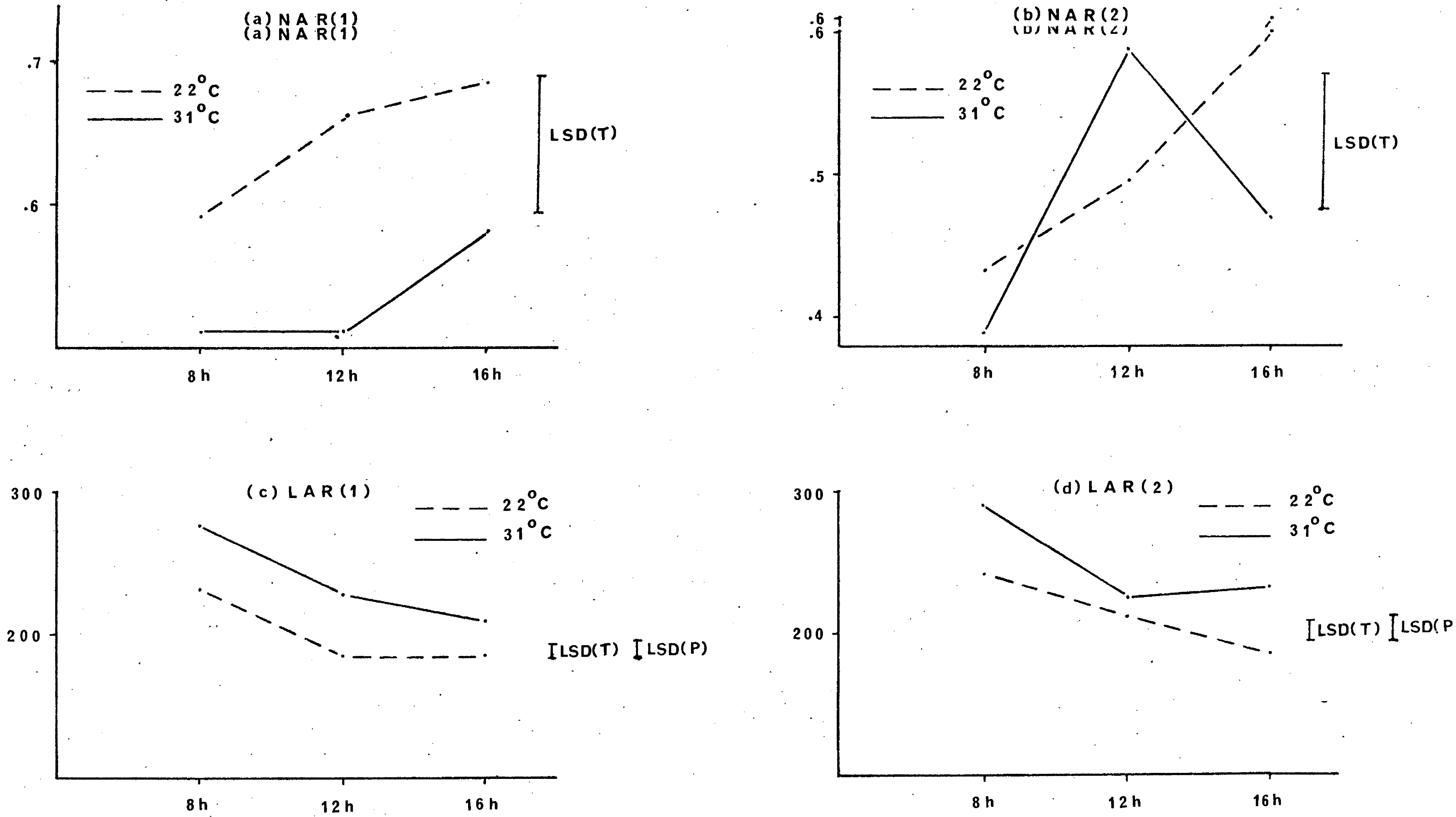


Figure 15 The effects of photoperiod at 22°C and 28°C night temperatures on the NAR and LAR of potted teak seedlings.

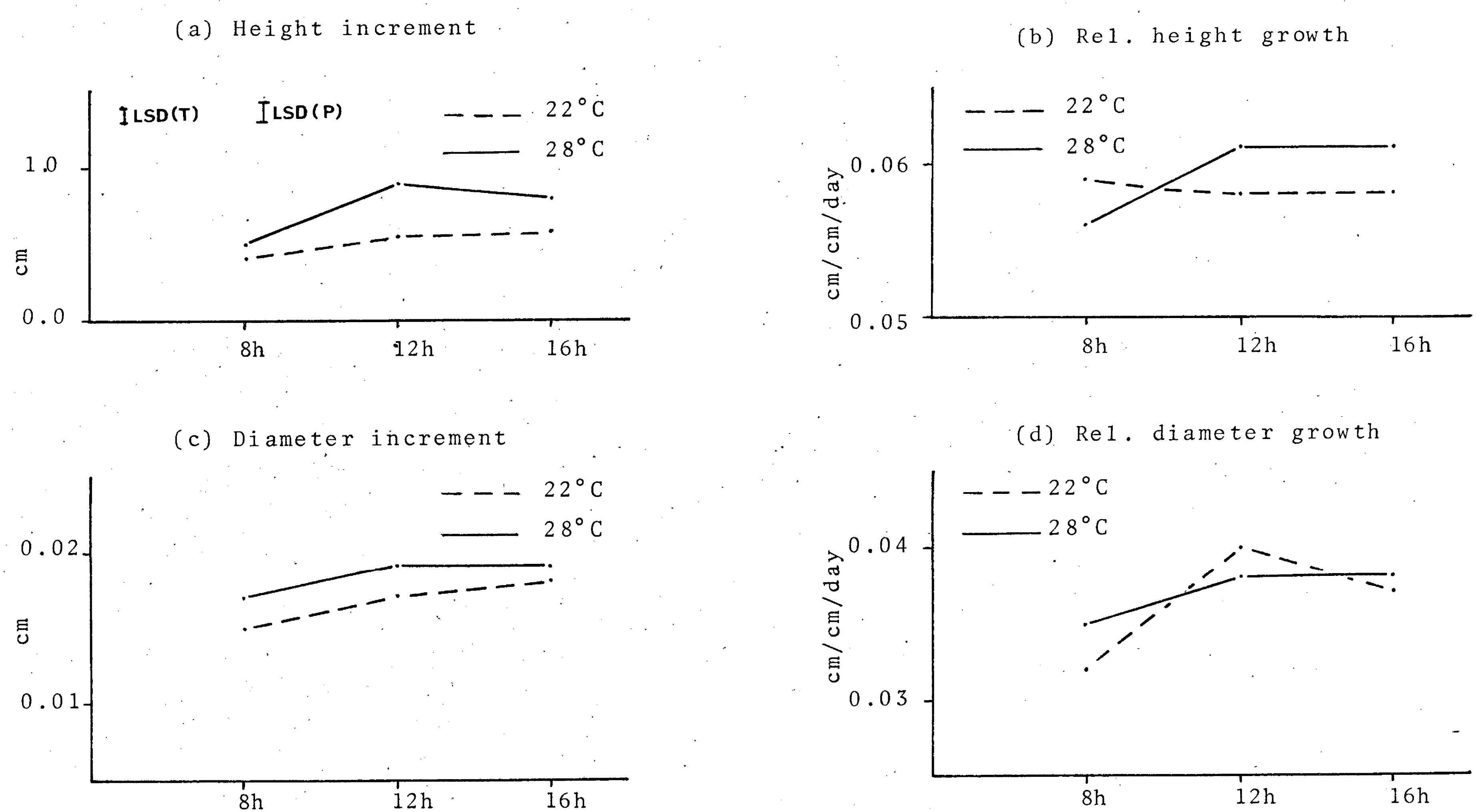


Figure 16 The response in height and diameter growth of teak seedlings to 8h, 12h and 16h photoperiods and, 22°C and 28°C night temperatures.

The variation in the mean values in period 2 was slightly greater (100 - 133 g/g/day), but the treatment differences were not significant. Thus, there was no effect on relative growth rate under the regimes applied in either period with daylength ranging between 8 - 16 hours at the two temperature regimes (33°/22°C and 33°/28°C).

Net assimilation rate. The NAR tended to decrease at higher night temperatures and shorter photoperiods (Figure 15a, b). In period 1, the value of NAR determined at the lower night temperature (22°C) (0.646 mg/cm^2/day) was significantly higher than that obtained under the higher night temperature (28°C) (0.534 mg/cm^2/day). Although the effect of photoperiod was not significant, there was a tendency for NAR to increase as photoperiod increased from 8 hours (0.552 mg/cm^2/day) to 16 hours (0.632 mg/cm^2/day).

The effects of photoperiod and temperature on NAR in period 2 were probably similar to the effects recorded in period 1. However, this could not be clearly demonstrated. The values for NAR at the lower night temperature exceeded those recorded at the higher night temperature at 8 hours and 16 hours photoperiods (Figure 15b). Under 12 hours photoperiod, however, the situation was reversed. The value determined at the 12 hours photoperiod in 33°/28°C temperature regimes was unusually large. This was due to the pairing in this regime of small seedlings at one harvest with abnormally large specimens at another, thus giving a very high NAR value. It was considered a more reliable value would have been somewhere within the range 0.391 - 0.469 mg/cm^2/day. If this amended value were to be applied in the analysis, NAR would vary inversely with the night temperature regimes as in period 1.

The effect of photoperiod on NAR was significant. The NAR tended to increase with the increase in photoperiod from 8 hours to 16 hours. This again was not clearly demonstrated at the higher night temperature due to the confusion at the 12 hours photoperiod mentioned above. The effect, however, was very clear at the lower night temperature (Figure 15b). It was considered that the NAR at the higher night temperature would generally follow a similar trend to that at the lower night temperature. Thus, the NAR has the tendency to decrease with the increase in night temperature from 33°/22°C to 33°/28°C and decrease in photoperiod from 16 hours to 8 hours.

Leaf area ratio. In contrast to NAR, the LAR increased with the increase in night temperature and the decrease in photoperiod. It exhibited a similar trend in both periods (Figures 15c, d) with the LAR value at the higher night temperature significantly greater than that at the lower night temperature applied. LAR also decreased significantly as photoperiod increased from 8 hours to 12 hours, but the decrease was not significant as the photoperiod was further increased from 12 hours to 16 hours. Thus LAR varies directly with night temperatures applied and inversely with the photoperiods between 8 hours and 12 hours.

Height growth. The effects of photoperiod and night temperature on height growth of teak seedlings were assessed both as height increment and relative height growth. Height increment was greater at the higher night temperature and longer photoperiod. The increment in height was significantly greater at 33°/28°C than at 33°/22°C. It also increased significantly as the photoperiod was increased from 8 hours to 12 hours. The difference however was not significant between the 12 hours and 16 hours photoperiods (Figure 16a).

The effects of both night temperature and photoperiods studied on the relative height growth were not significant. This was due to the seedlings being relatively larger at both the higher night temperature and under the longer photoperiods when the initial height measurements were taken. The initial height measurements were taken only on the 24th day of the treatment, and the seedlings at the higher night temperature and longer photoperiods were larger than those at the lower night temperature and shorter photoperiods (Table 39). This situation masked the effects of night temperature and photoperiod on the relative height growth rates of the seedlings. Possibly, had the seedlings been of the same size at the initial measurements, some effects of night temperature and photoperiod could have been demonstrated. Differences in relative height growth may of course have occurred before the 24th day to account for the large differences in total height present on that day.

From the measurements of the height increment and also from the heights of the seedlings at the initial height measurements taken on the 24th day of the treatment (Table 39), an effect on height growth of teak seedlings may be deduced. Height growth increased with night temperature from 22°C to

28°C and an increase in photoperiod from 8 hours to 12 hours. No significant response in height growth occurred with the change of photoperiod from 12 hours to 16 hours.

Table 39. Average height of seedling at initial height measurements taken on the 24th day of the treatment

Treatment	Average height in cm		
	8 hrs	12 hrs	16 hrs
33°/22°C	4.7	5.9	6.6
33°/28°C	6.3	9.9	8.6

Diameter growth. The effects of night temperature and photoperiod on diameter growth were assessed on both diameter increment and relative diameter growth. Diameter increment tended to increase with the increases in both night temperature and photoperiod. Diameter increment was greater at the higher night temperature (0.018 cm) than at the lower (0.017), but the difference was significant only at 10 per cent level. The effect of photoperiod on diameter increment was not significant, but showed a tendency to increase with the increase in photoperiod from 8 hours to 12 hours and then to level off with further increase of photoperiod to 16 hours (Figure 16c).

The effects on the relative diameter growth were also not significant, but did have similar trends to the result obtained for diameter increment (Figure 16d).

Thus, NAR, LAR, and height growth were significantly affected by night temperature and photoperiod studied. The LAR was greater at the higher night temperature and shorter daylength whilst the NAR was just the reverse, resulting in no effect on the RGR. The height growth increased at higher night temperature and longer photoperiod. In all cases, the responses to photoperiod were demonstrated only between 8 hours and 12 hours with no significant responses demonstrated between 12 hours and 16 hours.

13.3.2 Dry matter distribution

Relative growth of stem to total plant weight. The relative stem growth to total weight increased with the increase in night temperature and photoperiod (Figure 17). It was significantly greater at 33°/28°C (0.8020) than at 33°/22°C (0.7759) and was also significantly higher at the 12 hour (0.7998) than at the 8 hour (0.7636) photoperiod. The difference between the 12 hour and 16 hour (0.8033) photoperiod was not significant. Thus, more photosynthate was distributed towards the stem at 33° /28°C and 12 hour and 16 hour photoperiods. These results support the results of the effect of night temperature and photoperiods on height growth where better height growth was obtained at 33°/28°C and 12 hour and 16 hour photoperiod.

The effect of photoperiod and night temperature on relative growth of shoot to root, leaf to total weight, and

Table 43 Statistical analysis for dry matter distribution

Source of variation	df.	Mean squares			
		$\frac{\log_e \text{shoot}}{\log_e \text{root}}$	$\frac{\log_e \text{root}}{\log_e \text{total wt}}$	$\frac{\log_e \text{stem}}{\log_e \text{total wt}}$	$\frac{\log_e \text{leaf}}{\log_e \text{total wt}}$
Temperature	1	0.000340	0.000137	0.005109**	0.000140
Photoperiod	2	0.004045	0.001121	0.004841**	0.000083
Grade	4	0.003203	0.000808	0.000032	0.000074
Photo. x Temp.	2	0.001796	0.000520	0.000094	0.000035
Grade x Temp.	4	0.003150	0.000830	0.000154	0.000038
Grade x Photo.	8	0.001062	0.000267	0.000302	0.000022
Error	8	0.001583	0.000381	0.000248	0.000049

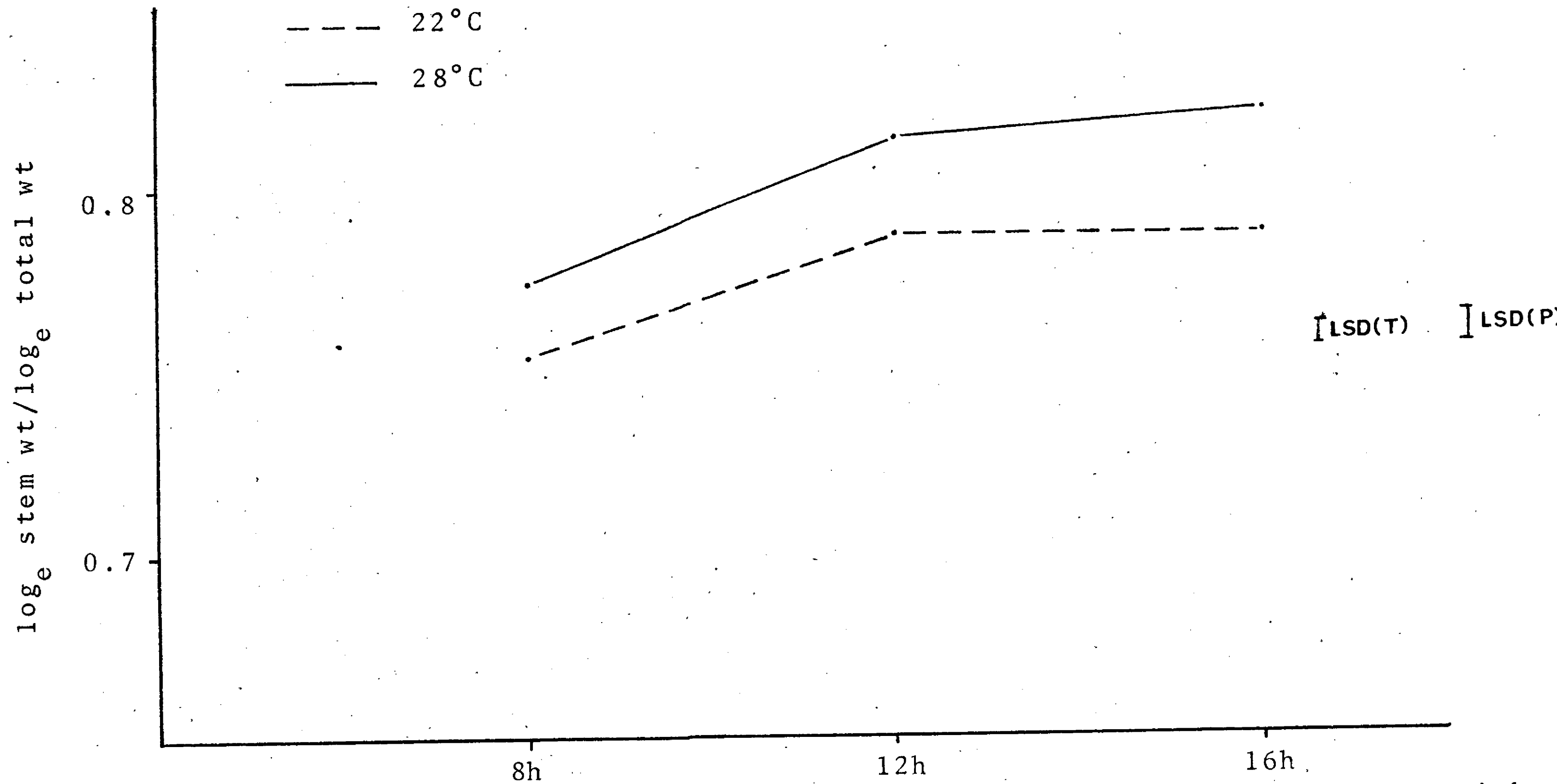


Figure 17 The increase in distribution of dry matter towards the stem with the increase in photoperiod from 8 h to 12 h and the night temperature from 22°C to 28°C.

root to total weight was not significant. This indicated that the change in photoperiod and night temperature within the limits studied did not change the distribution of dry matter towards the leaf and the root.

13.4 Discussion and conclusion

The net assimilation rate, leaf area ratio, height growth and distribution of photosynthate towards the stem are affected by both the night temperature and photoperiod regimes studied.

The net assimilation rate was greater at the lower night temperature and longer photoperiod while leaf area ratio exhibited a reverse trend. This resulted in the relative growth rate appearing unaffected by both temperature and photoperiod as RGR = NAR x LAR.

Height growth was better at both the higher night temperature and the longer photoperiods. This result was supported by the similar trend demonstrated by the pattern of distribution of photosynthate towards the stem.

In all cases a response to photoperiod was demonstrated only between eight hours and 12 hours, and the difference in response between 12 hours and 16 hours was not significant. Since the daylengths in the regions of natural teak zone exceed 12 hours, it appears photoperiod is likely to be of minor importance to the development and growth of teak. The effect of temperature suggests a detailed study of responses of teak to this climatic variable would be valuable.

CHAPTER XIV

EXPERIMENT ON GERMINATION OF TEAK SEED FROM FIVE DIFFERENT PROVENANCES

14.1 Object

To study the differences in germination of teak seed from Northern Burma (Myitkyina), Southern Burma (Toungoo), India (Kerala State), Java (Pati), and Laos (Pakse).

14.2 Materials and methods

The experiment was conducted in the phytotron in C.S.I.R.O. Canberra. Teak seeds from Northern Burma, Southern Burma, India, Java and Laos origins were pretreated by alternately soaking in running tap water at room temperature for 24 hours, and drying in the open glasshouse at 30°/25°C for 24 hours. The process was repeated for three weeks and the pretreated seeds were sown in 18 cm top diameter plastic pots containing a mixture of 3:2 perlite and vermiculite growth medium. The seeds were covered with approximately 0.5 cm thickness of the same growth medium mixture.

Twenty seeds were sown in each pot, and a replicate of 20 x 20 seeds were used for each provenance. The pots were placed in troughs containing water approximately 2.5 cm high and this water level maintained throughout the experiment. The seeds from all five provenances were set out to germinate in a 36°/31°C open glasshouse, and were watered from above at 8.30 a.m. and 3.30 p.m. daily.

Germination was recorded each day and as seeds germinated they were pricked out the same day and sown in 8 cm top diameter pot containing the same growth medium mixture.

14.3 Results

Results were calculated using Czabator's method as described in sub-section 5.4.3. They were as given in Tables 44 and Figure 18, and analysis of variance in Appendix V.

Table 44. Results of germination of provenances studied

Provenances	Peak value	Mean daily germination	Germination value
Java	3.3236	1.5188	5.2824
Burma (S)	1.7158	0.9938	1.9098
India	0.8737	0.4563	0.4837
Burma (N)	0.6410	0.3875	0.3299
Laos	0.5752	0.3563	0.3202

The values quoted are the mean values of 20 observations, consequently the quoted germination values (GV) do not exactly equal the product of the corresponding peak value (PV) and mean daily germination (MDG).

Similarly results were obtained for speed of germination (peak value), and total germination (mean daily germination) and consequently for germination value. Thus there was no interaction with provenance between speed and totality of germination.

The germination of the Javanese seed was far better than that of the other provenances. The PV (3.32)

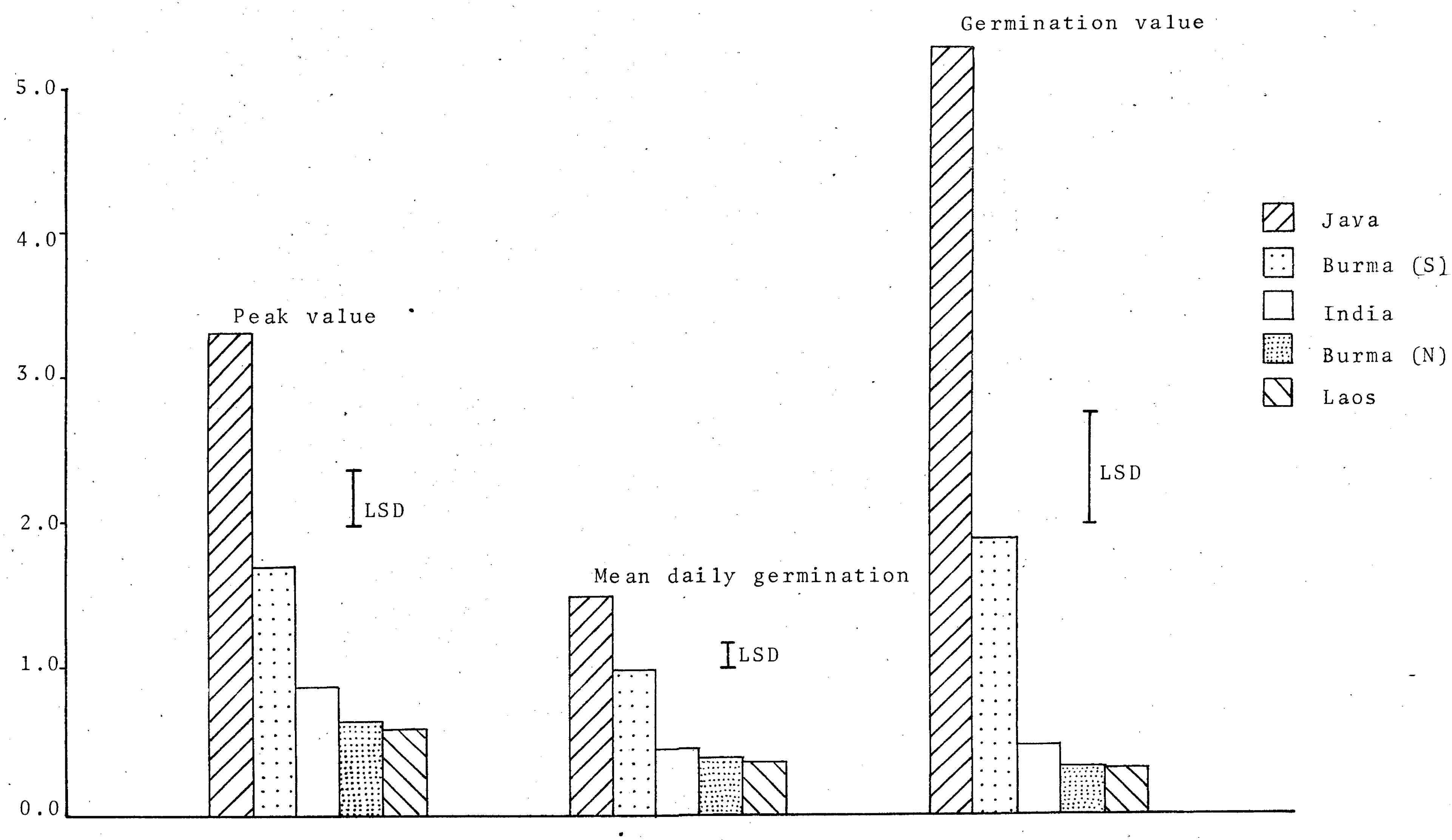


Figure 18. Comparative values for peak value, mean daily germination and germination value of the five provenances studied.

recorded for this provenance was almost double that recorded for any other provenance, and the MDG value also exceeded other results by more than 50 per cent. The GV of the Javanese provenance was significantly superior to the Southern Burmese provenance at the 0.1 per cent level. The Southern Burma provenance in turn was significantly (0.1 per cent level) better than the Indian, Northern Burmese and Laotian provenances in speed and totality of germination. Differences between the Indian, Northern Burmese and Laotian provenances were however not significant (5 per cent level).

14.4 Discussion and conclusion

It should be noted the conditions for germination were based on a preliminary experiment using seed from a tropical source (Papua New Guinea). The superiority of the more tropical sources may have been due at least in part to these being better suited to the 36°C regime than were the less tropical provenances. The less tropical sources might be better at lower temperatures. Space did not allow detailed study of this but small scale check experiments indicated generally poor germination at 30°C. Consequently the results of the experiment may be interpreted as indicating real differences in the seed quality of the batches used.

Germination of teak seed, however, can be affected by period and condition of storage and time of seed collection (see sections 5.2 and 5.3). As particulars on storage and time of collection of seeds from India, Java and Laos were not available, it is not possible to draw definite conclusion from the results obtained. Moreover, the seeds from Java appeared to have been graded and possibly selected for quality, as they were both uniform and of a larger size than all other provenances. In contrast there were large variations in seed size in the other provenances. Possibly, the grading was due to the usual Java practice of only sowing seed of 14 mm diameter or greater (Gärtner, 1956). If so, these results would support the practice.

However, seeds from the two Burmese provenances were known to have been collected at the same time and stored under identical conditions. Thus, these two provenances may be expected to be comparable. The superiority in germination of the Southern Burmese provenance to that of Northern Burmese supports the results of observations in Burma. Seeds from the southern part of the country have been reported to always germinate better than seeds from the northern part (see section 5.3). Thus, it is possible a real provenance difference in seed quality and germination does exist.

Seed production and seed viability may thus be related to locality, with the more tropical areas giving superior yields. Further study of this is needed, but if this is so, then serious consideration would need to be given to siting seed orchards in favourable localities.

Clearly in Burma if good germination is required, seed collection should be carried out in the south rather than in the northern part of the country. This should be strictly adhered to especially when good germination is required for extensive plantation establishment in the southern part of the country. For plantation establishment in northern areas, poor germinations may have to be tolerated if clear provenance differences in performance are found.

CHAPTER XV

AN EXPERIMENT TO COMPARE THE EFFECT OF DAY AND NIGHT TEMPERATURES ON DEVELOPMENT OF FIVE PROVENANCES OF TEAK SEEDLINGS

15.1 Object

To compare the response of teak seedlings from Myitkyina (Northern Burma), Toungoo (Southern Burma), Kerala State (wet part of India), Pati (Java) and Pakse (Laos) under various combinations of day and night temperature regimes (6 treatments). The areas included in this experiment form part of five of the 16 provenances proposed in Chapter X as constituting the basic minimum for provenance variation studies of teak.

15.2 Materials and methods

The original plan for the experiment proposed five pairs of seedlings of each provenance should be included in each treatment. One seedling from each pair was to be harvested 14 days and the other 28 days after commencement. Although 400 seeds of each provenance were sown, the germination was so slow and sporadic that all provenances except Java and Southern Burma gave too few seedlings for the full layout to be possible. The intermittent germination also meant seedlings varied in size, and the seedlings were therefore graded to allow this size variation to be distributed evenly between treatments. The variation in time of germination also made it necessary for the experiment to be carried out in four overlapping periods. The number of seedlings available thus varied from provenance to provenance and treatment to treatment. Full details of the number of pairs of seedlings for each provenance and under each treatment are given in Table 45.

Table 45. Number of pairs of seedlings used for each provenance and each treatment

Provenance	Number of pairs of seedlings at					
	30°/22°C	30°/31°C	33°/22°C	33°/31°C	36°/22°C	36°/31°C
Northern Burma	5	2	5	5	1	5
Southern Burma	5	5	5	5	5	5
India	5	5	5	5	3	5
Java	5	5	5	5	5	5
Laos	1	1	4	4	2	5

The seedlings used were those germinated for the provenance germination experiment (see section 14.2 for details of seed pretreatment and germination).

Due to space limitations, one of the paired plants was planted in a 10 cm and the other in a 15 cm top diameter plastic pot using a 1:1 mixture of perlite and vermiculite as the potting medium. The plants in 10 cm diameter pots were used for the first sampling and those in 15 cm diameter pots were used for the final sampling.

Immediately after potting, the seedlings were set out in the respective open glasshouses. With the exception of the seedlings allotted to the 36°/31°C open glasshouse, seedlings under all other treatments had to be moved from one glass-house to another on trolleys to get the required combinations of day and night temperatures. The seedlings were moved at 8.30 a.m. for their respective day temperatures and 4.30 p.m. for the night temperatures. Watering was carried out three times a day using modified Hoagland nutrient solution (Appendix III) at 8.30 a.m. and tap-water at 12 noon and at 3.30 p.m.

One seedling of each pair was harvested on the 14th day and the other on either the 28th or 29th day from the start of the treatment. At both harvests leaf area, and dry weights of the roots and leaves were determined. Seedlings in the second harvest only were measured for height and diameter on the 19th and either the 28th or 29th day. Leaf area was measured by means of an airflow planimeter. Plant heights were measured from cotyledon level to the point where the last pair of leaves split, and diameter measurements were taken at mid point between the first and the second pair of leaves in the direction parallel to the second pair of leaves.

The results were divided into (a) overall growth and dry matter production and (b) distribution of dry matter.

Relative growth rate, net assimilation rate and leaf area ratio were calculated using the following formulae detailed in Chapter XI

$$\text{Relative growth rate (RGR)} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

where W_1 and W_2 = total dry weight at time 1 and 2 and

t_1 and t_2 = time 1, and time 2

$$\text{Net assimilation rate (NAR)} = \frac{W_2 - W_1}{A_2 - A_1} \times \frac{\log_e A_2 - \log_e A_1}{t_2 - t_1}$$

where, W_1 and W_2 = total dryweight at time 1 and 2

A_1 and A_2 = total leaf area at time 1 and 2

t_1 and t_2 = time 1 and time 2.

$$\text{Leaf area ratio (LAR)} = \frac{L_A}{W},$$

where L_A = total leaf area

W = total dry weight

The distribution of dry matter was calculated using the allometric formula

$$\log_e(y) = a + k.\log_e(x),$$

where x and y = any portion of a plant

a and k = constants

The constant k, which is the slope of the regression gives the relative growth rate of 'y' in relation to 'x'. Using this formula, the relative growth rates of shoot to root, root weight to total dry weight, stem weight to total dry weight and leaf weight to total dry weight were calculated for every provenance in each treatment.

Standard analysis of variance was followed, and where a significant difference between means was found to exist, the means were subjected to L.S.D. test (see Steel and Torrie 1960) for individual comparison. The major effects analyzed were provenance, day temperature and night temperature. The two way interactions between these factors were also examined.

Table 46. Summary of the results of all the parameters studied in the provenance experiment

	Diameter Increment (cm/day)	Relative Diameter Growth (cm/cm/day)	Height Increment (cm/day)	Relative Height Increment (cm/cm/day)	Relative Growth Rate (g/g/day)	Net Assimilation Rate (mg/cm^2/day)	Leaf Area Ratio		Log$_e$shoot/Log$_e$Root	Log$_e$leaf/Log$_e$ Total wt.	Log$_e$stem/Log$_e$ Total wt.	Log$_e$root/Log$_e$ Total wt.
							1. (cm^2/g)	2. (cm^2/g)				
Provenance	** Bur(N) 0.012 Laos 0.012 Java 0.012 Bur(S) 0.012 India 0.009	* Bur(S) 0.034 Java 0.033 Bur(N) 0.033 Laos 0.033 India 0.027	N.S. Bur(N) 0.312 Laos 0.251 Java 0.249 India 0.242 Bur(S) 0.237	* Java 0.050 Bur(N) 0.047 Bur(S) 0.045 Laos 0.040 India 0.039	N.S. Java 0.112 Bur(N) 0.106 Bur(S) 0.103 Laos 0.100 India 0.091	N.S. Java 0.516 India 0.507 Bur(N) 0.505 Bur(S) 0.487 Laos 0.456	** Laos 212.5 Bur(N) 207.7 Java 206.8 Bur(S) 197.3 India 176.1	* Laos 229.8 Bur(N) 228.7 Java 226.5 Bur(S) 223.7 India 193.6	N.S. Laos 1.099 Java 1.095 Bur(N) 1.054 India 1.008 Bur(S) 0.982	N.S. Laos 1.142 Java 1.088 Bur(S) 1.087 India 1.072 Bur(N) 1.050	N.S. India 0.895 Bur(N) 0.832 Bur(S) 0.759 Java 0.752 Laos 0.688	N.S. Bur(S) 0.956 India 0.944 Bur(N) 0.932 Java 0.891 Laos 0.887
Day Temperature	** 36° 0.014 33° 0.011 30° 0.009	** 36° 0.039 33° 0.030 30° 0.027	* 36° 0.301 33° 0.246 30° 0.227	N.S. 36° 0.047 33° 0.043 30° 0.043	N.S. 36° 0.108 33° 0.102 30° 0.097	** 36° 0.606 33° 0.465 30° 0.412	** 30° 221.8 33° 206.7 36° 171.8	** 30° 242.9 33° 229.7 36° 188.7	30° 1.093 36° 1.083 33° 0.967	N.S. 30° 1.130 33° 1.072 36° 1.062	N.S. 33° 0.817 36° 0.811 30° 0.727	** 33° 0.996 36° 0.920 30° 0.850
Night Temperature	** 31° 0.013 22° 0.009	* 31° 0.033 22° 0.031	** 31° 0.390 22° 0.126	** 31° 0.056 22° 0.033	** 31° 0.117 22° 0.088	N.S. 22° 0.503 31° 0.486	** 31° 228.1 22° 172.0	** 31° 254.8 22° 186.1	* 22° 1.100 31° 0.995	** 22°C 1.135 31°C 1.041	** 31° 0.892 22° 0.678	** 31° 0.972 22° 0.872
Provenance x Night	* Laosx31° 0.014 Javax31° 0.014 Bur(N)x31° 0.014 Bur(S)x31° 0.013 Indiax31° 0.011 Bur(N)x22° 0.011 Bur(S)x22° 0.011 Javax22° 0.009 Laosx22° 0.009 Indiax22° 0.007	N.S.	N.S.	* Javax31° 0.065 Laosx31° 0.057 Bur(N)x31° 0.056 Bur(S)x31° 0.056 Indiax31° 0.045 Bur(N)x22° 0.037 Javax22° 0.036 Bur(S)x22° 0.034 Indiax22° 0.033 Laosx22° 0.024	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	* Bur(S)x31° 1.020 Bur(N)x31° 0.992 Javax31° 0.986 Indiax22° 0.958 Laosx31° 0.931 Indiax31° 0.930 Bur(S)x22° 0.893 Bur(N)x22° 0.873 Laosx22° 0.843 Javax22° 0.795
Provenance x Day	* Bur(N)x36° 0.016 Javax36° 0.015 Laosx36° 0.015 Bur(S)x36° 0.013 Bur(S)x33° 0.013 Javax33° 0.012 Indiax36° 0.012 Bur(N)x33° 0.011 Laosx33° 0.011 Bur(N)x30° 0.010 Laosx30° 0.009 Bur(S)x30° 0.009 Indiax33° 0.009 Javax30° 0.008 Indiax30° 0.007	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Day x Night		* 36°x22° 0.041 36°x31° 0.038 33°x31° 0.033 30°x31° 0.030 33°x22° 0.028 30°x22° 0.023	* 36°x31° 0.484 33°x31° 0.350 30°x31° 0.336 33°x22° 0.142 36°x22° 0.119 30°x22° 0.119	N.S.	N.S.	N.S.	N.S.	* 30°x31° 399.3 33°x31° 353.4 36°x31° 309.0 33°x22° 283.2 30°x22° 267.1 36°x22° 219.5	N.S.	N.S.	N.S.	* 33°x31° 1.068 36°x31° 0.999 33°x22° 0.925 30°x22° 0.851 30°x31° 0.849 36°x22° 0.841

N.S. = Not Significant
* = Significant at 5% level
** = Significant at 1% level

Missing plot substitution (see Freese, p. 50, 1967) was used in the assessment of relative growth of shoot to root for the Laotian provenance at 30°/22°C, as the results obtained appeared abnormally small.

15.3 Results

15.3.1 Overall growth and dry matter production

The results recorded are detailed in Table 46 and Figures 19 to 21, and analyses of variance in Appendix VII. More detailed results are given in Appendix VI.

(i) Diameter growth. Diameter growth was assessed both as diameter increment and relative diameter growth.

Analysis of the results of diameter increment gave significant interactions between provenance and day temperature, and provenance and night temperature (Table 46).

There appear to be definite differences between provenance in diameter increment (Table 46). For simplicity, rankings are given below with lines linking treatments which did not differ significantly:

36°C (Day)	33°C (Day)	30°C (Day)
Burma (N)	Burma (S)	Burma (N)
Java	Java	Laos
Laos	Burma (N)	Burma (S)
Burma (S)	Laos	Java
India	India	India

The northern Burmese provenance was always amongst the best in diameter increment, and was never significantly below any other provenance (Figure 19.2). Java was as good as Northern Burma at 36°C and 33°C, but significantly poorer at 30°C. Southern Burma on the other hand was also as good as Northern Burma at 33°C and 30°C, but significantly poorer at the higher temperature of 36°C. Laos was marginally significantly poorer than Southern Burma at 33°C (LSD = 0.0017, with the difference being 0.0019). This provenance however was among the best at 36°C and 30°C. The Indian provenance was poorest in all the day temperature regimes studied.

Within each provenance, diameter increment increased with day temperature from 30°C to 36°C (Figure 19.2). However, some differences were not significant and the details are depicted diagrammatically below:

Burma (N)	Burma (S)	India	Java	Laos
36°C	36°C	36°C	36°C	36°C
33°C	33°C	33°C	33°C	33°C
30°C	30°C	30°C	30°C	30°C

The general trend however was for an increase in diameter increment with increase in temperature from 30°C to 36°C, which suggested all provenances studied preferred the higher day temperature.

Night temperature also had a marked effect on diameter increment, being significantly higher at 31°C than at 22°C (Table 46, Figure 19.1). The details of the night temperature x provenance interactions are given below:

31°C (Night)	22°C (Night)
Laos	Burma (N)
Java	Burma (S)
Burma (N)	Java
Burma (S)	Laos
India	India

Within all provenances, the performance was significantly better at the higher night temperature (31°C). The Indian provenance again gave the poorest performance in diameter increment at both the night temperatures. Northern Burma was among the best under both the night temperature regimes. Javanese and Laotian provenances were as good as Northern Burmese at 31°C, but significantly inferior at 22°C. Southern Burma was significantly poorer than the provenances from Laos, Java, and Northern Burma at 31°C, but was not significantly different from any of these at 22°C. Thus, the diameter increment increased with the increase in night temperature from 22°C to 31°C. Once again, Northern Burma was among the best and India the poorest at both the temperatures.

The results of the relative diameter increment was rather confusing as the initial measurements were taken only on the 19th day of the treatment when the sizes of the seedlings already varied. This tended to mask the effect of the treatments. However, although there was an interaction between night and day temperatures, there was an indication that relative diameter increment was superior at both higher day and higher night temperatures (Figure 19.4). The results are shown diagrammatically below:

<u>31°C (Night)</u>	<u>22°C (Night)</u>
36°C 33°C 30°C	36°C 33°C 30°C

<u>36°C (Day)</u>	<u>33°C (Day)</u>	<u>30°C (Day)</u>
22°C 31°C	31°C 22°C	31°C 22°C

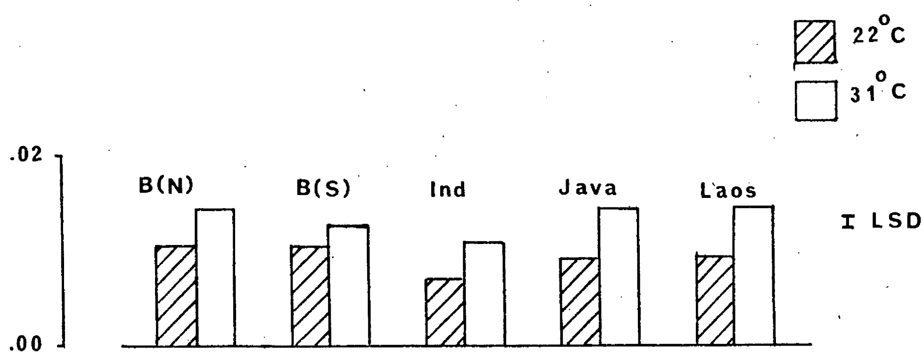


Figure 19.1 Diameter increments of the five provenances studied under 22°C and 31°C night temperatures.

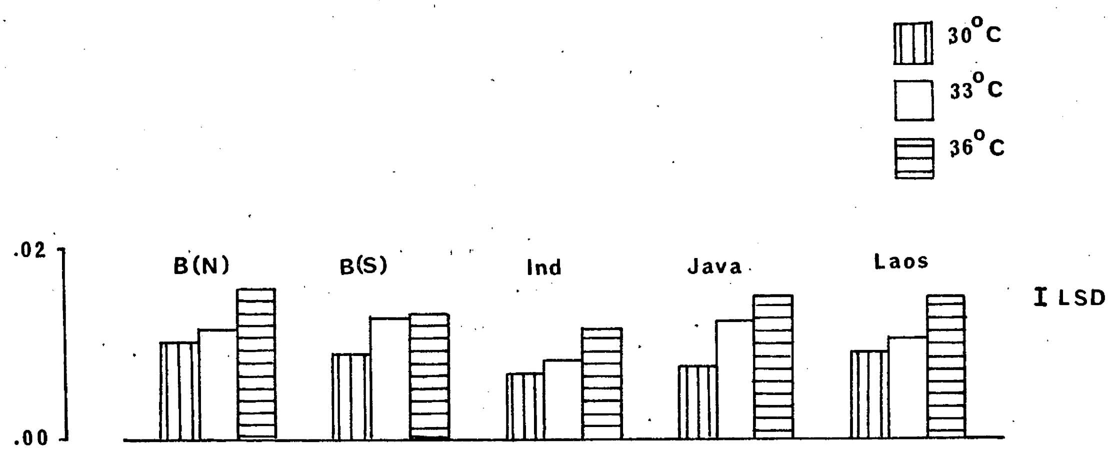


Figure 19.2 Diameter increments of the five provenances studied under 30°C, 33°C and 36°C day temperatures.

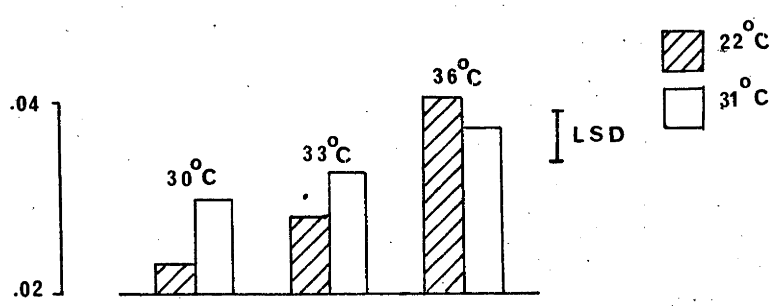


Figure 19.3 The relative diameter growth of teak seedlings at 30°C, 33°C and 36°C day temperatures and 22°C and 31°C night temperatures.

As in the diameter increment, the Indian provenance was significantly the poorest in relative diameter increment (Table 46), thus supporting the results of the diameter increment.

The diameter growth therefore increased with the increase in both day and night temperatures studied. Northern Burmese provenance was amongst the best in all the treatments, whilst India was the poorest. The relative performance of other provenances changed slightly with the day and night temperatures. There were indications that the Southern Burmese provenance was unfavourable in diameter growth at the higher day and night temperatures studied. This provenance gave its best performance at 33°/22°C day/night temperatures.

(ii) Height growth. Height growth was also assessed both as height increment and relative height increment.

There were no significant differences in height increment of the provenances studied. At 31°C night temperature, the height increment was significantly greater at 36°C than at 33°C day temperatures with the difference between 33°C and 30°C not significant. At 22°C night temperature, the effect of day temperature on height increment was not significant, but showed a tendency for better growth at the two higher day temperature (Figure 20.1).

Despite a significant day x night temperature interaction height increment was significantly greater at the higher night temperature than at the lower night temperature studied. The effect of day temperature on height increment was however confused due to the interaction effect. The results are shown diagrammatically below:

31°C (Night)	22°C (Night)
36°C	33°C
33°C	36°C
30°C	30°C

Thus, height increment of teak is generally favoured by higher temperature, particularly higher night temperature.

As in the relative diameter increment, the initial measurements for the relative height increment were taken only on the 19th day of the treatment when the seedlings already varied in size due to treatment effect. There was a significant interaction effect between provenance and night temperature (Table 46 and Figure 20.2) and the results are depicted diagrammatically below:

31°C (Night)	22°C (Night)
Java	Burma (N)
Laos	Java
Burma (N)	Burma (S)
Burma (S)	India
India	Laos

At 31°C night temperature the relative height growth of the Southern Burmese provenance was only marginally significantly poorer than that of the Javanese provenance. This difference was almost non significant (being 0.0088, and LSD = 0.0089) and was therefore ignored. The Indian provenance was significantly poorest in relative height growth at 31°C, but was not significantly different from the best provenance (Northern Burma) at 22°C night temperature. The Laotian provenance on the other hand performed well in relative height growth at 31°C night temperature, but was significantly the poorest at 22°C, suggesting unsuitability of this provenance

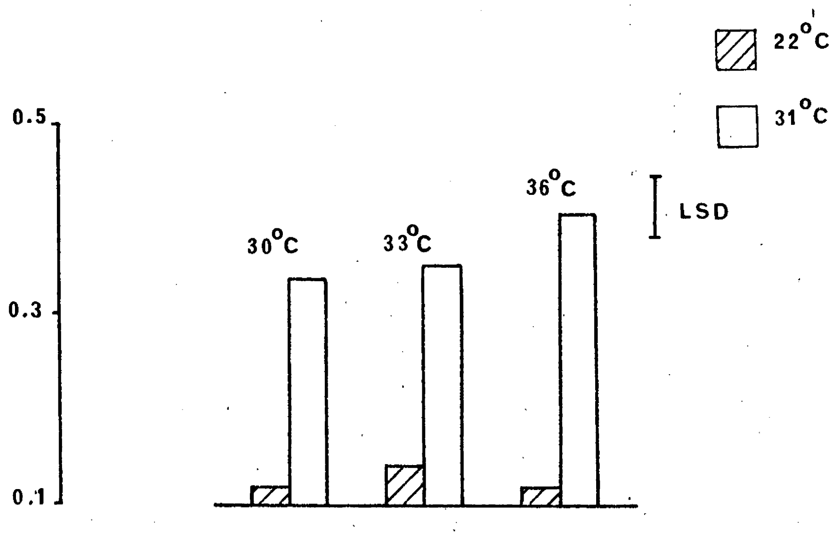


Figure 20.1 Height increment of teak seedlings at 30°C, 33°C and 36°C day temperatures and 22°C and 31°C night temperatures.

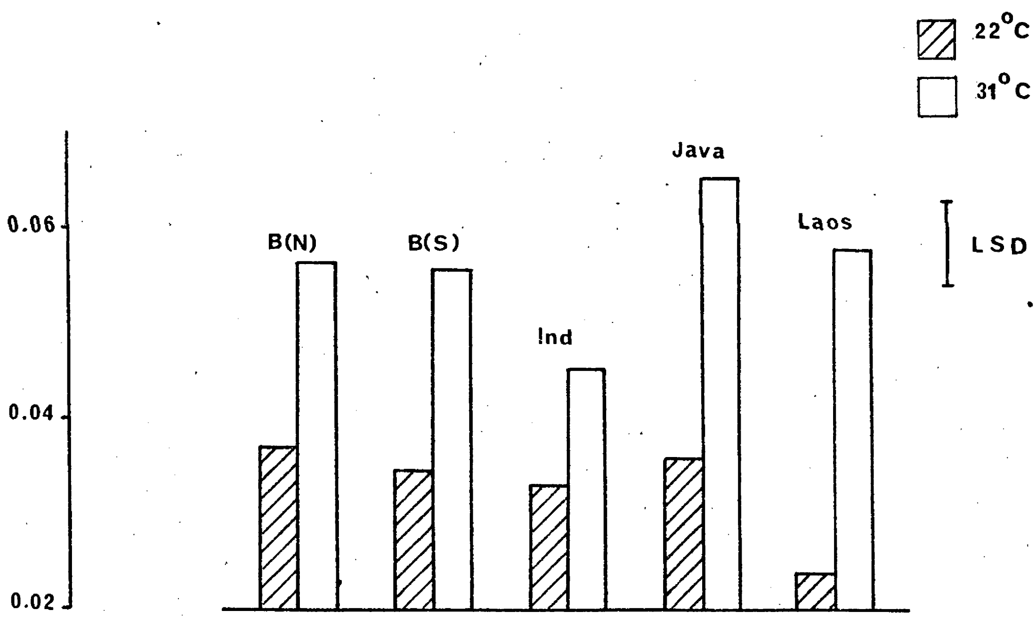


Figure 20.2 The relative height growth of the provenances studied under 22°C and 31°C night temperatures.

for the lower night temperature. The remaining three provenances were not affected significantly by the change in night temperature studied. Although the results were considered confusing, the performance of Laotian and Indian provenances in height growth agreed with their performance in diameter increment. This indicated the Indian provenance was generally poor in stem growth and the Laotian provenance was more suitable for 31°C than 22°C night temperatures.

Relative height growth of teak seedlings in general was significantly greater at the higher night temperature than at the lower night temperature for all provenances, and this was in agreement with the results of height increment.

(iii) Relative growth rate. The relative growth rate (RGR) was affected only by the change in night temperature. It was significantly higher at 31°C (0.1168g/g/day) than at 22°C (0.0879g/g/day) night temperature. The effects due to provenance and day temperature were not significant although the RGR of the provenances varied within the range 0.0912 - 0.1115g/g/day and that of day temperature within the range 0.0972 - 0.1084g/g/day.

(iv) Net assimilation rate. The net assimilation rate (NAR) was affected only by day temperature. It was significantly greater at 36°C (0.6057mg/cm^2/day) than at 33°C (0.4647mg/cm^2/day) and 30°C (0.4123mg/cm^2/day) with the differences between 33°C and 30°C not significant (Figure 21.1). No significant effects of provenance and night temperature were found, but the NAR value for individual provenances ranged from 0.4562 - 0.5162mg/cm^2/day.

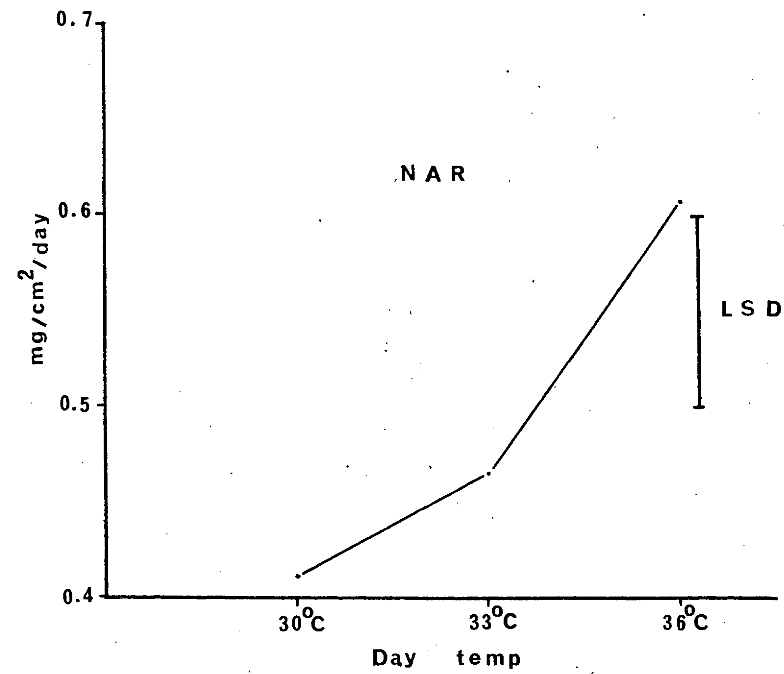


Figure 21.1 The increase in NAR with the increase in day temperature from 30°C to 36°C

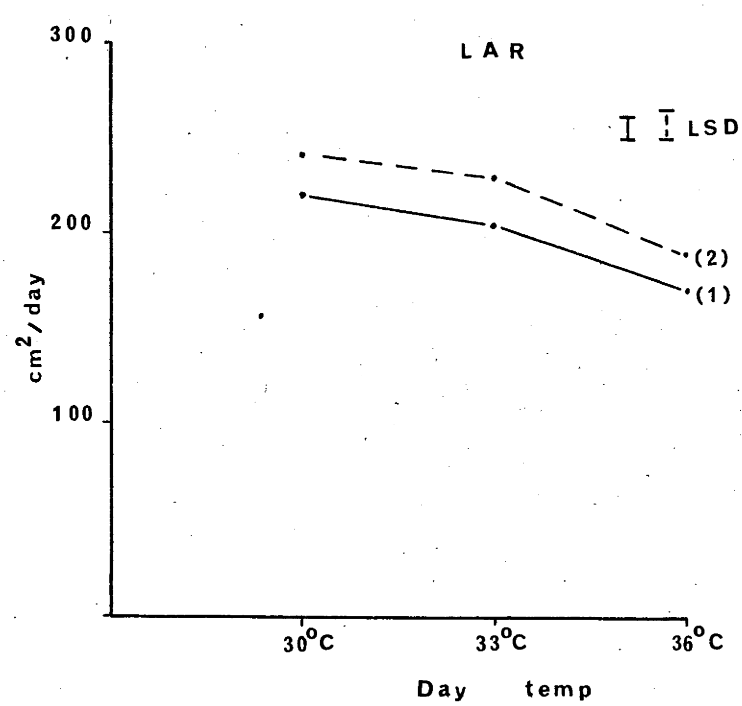


Figure 21.2 The decrease in LAR with the increase in day temperature from 30°C to 36°C

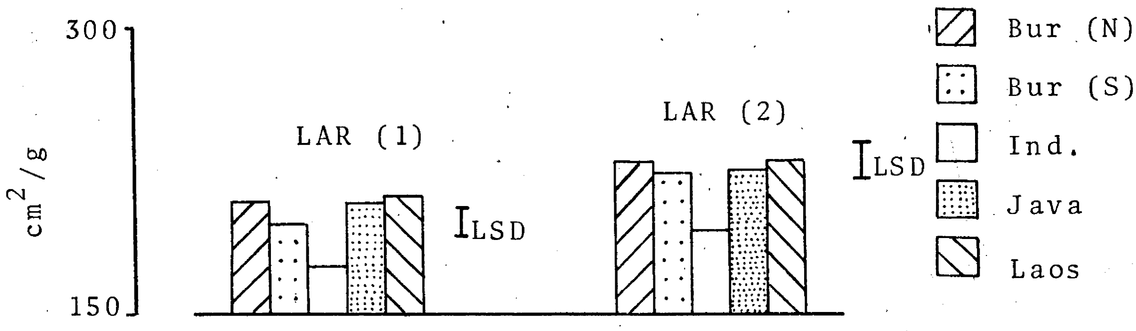


Figure 21.3 The comparative values of the LAR of the five provenances studied

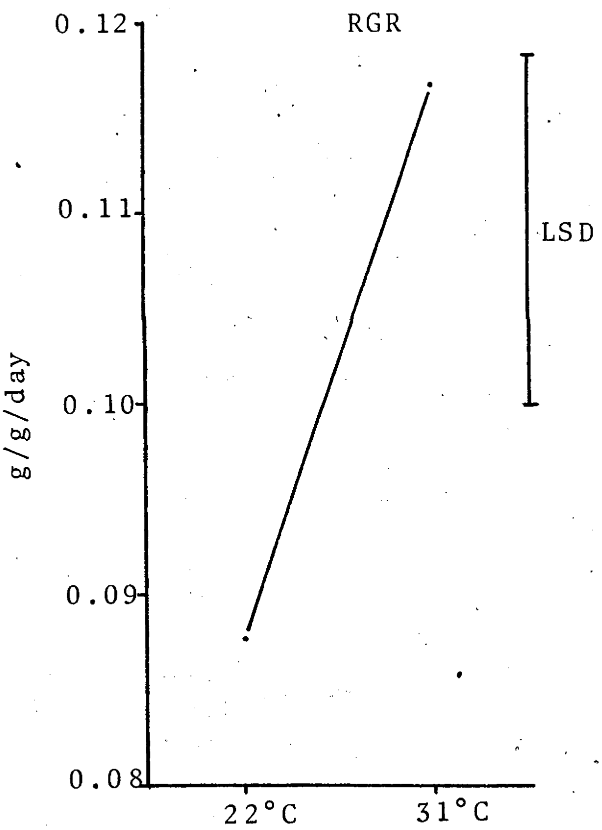


Figure 21.4 The increase in RGR with the increase in night temperature from 22°C to 31°C

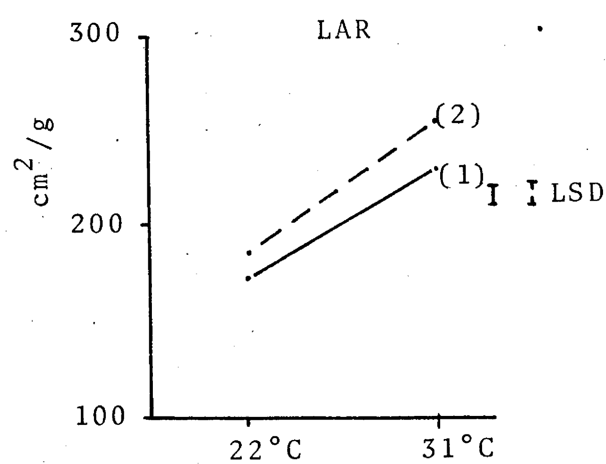


Figure 21.5 The increase in LAR with the increase in night temperature from 22°C to 31°C

(v) Leaf area ratio. The leaf area ratio (LAR) was assessed at both the initial and the final measurements and a similar trend was demonstrated in each. The effects of day temperature and night temperature and provenance were significant in both measurements.

Within the provenances studied, the Indian provenance had significantly the smallest leaf area ratio (Table 46 and Figure 21.3). The differences between the remaining provenances were not significant.

At the initial measurements, the LAR increased at lower day temperatures and higher night temperature (Table 46). The LAR was significantly different at the day temperatures of 36°C (171.8cm^2/g) and 33°C (206.7cm^2/g), and also between 33°C and 30°C (221.8cm^2/g) (Figure 21.2). The LAR also decreased significantly when the night temperature was reduced from 31°C (228.2cm^2/g) to 22°C (172.0cm^2/g). Thus, LAR increased inversely with day temperature and directly with night temperature studied.

At the final measurement, a significant interaction effect between day and night temperature was found. The LAR for the night temperature followed the same pattern as in the initial measurements (Table 46). The LAR at the three day temperatures exhibited a similar trend to that determined in the initial measurement. However, at the lower night temperature, there was no significant difference in LAR at 30°C and at 33°C, but the difference between 36°C and 33°C was significant (Table 46).

15.3.2 Distribution of dry matter

The results were as given in Table 46 and Figure 22, and analyses of variance in Appendix VII. More detailed results are given in Appendix VI.

(i) Relative growth of shoot to root. The relative growth of shoot to root was affected by both the day and night temperatures but no significant differences were found between provenances. However, the analysis of variants revealed the effect of day temperature as slightly below the 5 per cent significant level (4.734 and tabulated F = 4.74), but this was considered sufficiently close tobe regarded as significant.

The relative growth of shoot to root was significantly poorer at 33°C (0.967) than at 36°C (1.083) and 30°C (1.093) day temperatures with the difference between 30°C and 36°C not significant (Figure 22.1). Also, the relative growth of shoot to root at 31°C night temperature (0.995) was significantly poorer than at 22°C (1.100) (Figure 22.1). This indicated that less photosynthate was distributed towards the shoot, and more towards the root at 33°C day temperature and 31°C night temperature than at the other day and night temperatures studied.

(ii) Relative growth of root weight to total weight. There was a significant interaction effect between (a) day and night temperatures, and (b) provenance and night temperatures on the relative growth of root weight with respect to total weight (Table 46, Figures 22.2 and 22.3).

31°C (Night)	22°C (Night)
33°C	33°C
36°C	30°C
30°C	36°C

As illustrated, the relative growth of root at 31°C night temperature was significantly poorer at the 30°C day temperature whilst at the 22°C night temperature, it was significantly poorer at both 30°C and 36°C day temperatures. The results indicated more photosynthate was distributed towards the root at 33°C day temperature.

36°C (Day)	33°C (Day)	30°C (Day)
31°C	31°C	22°C
22°C	22°C	31°C

The pattern for night temperature differences shown above indicates the relative growth of root was significantly higher at 31°C than at 22°C night temperatures at both 36°C and 33°C day, but not at 30°C day temperature (Figure 22.3). This suggests more photosynthate was distributed towards the root at the higher than at the lower night temperature studied if the day temperature was also high. However, the effect of night temperature on distribution of photosynthate towards the root was masked at the lowest day temperature (30°C).

31°C (Night)	22°C (Night)
Burma (S)	India
Burma (N)	Burma (S)
Java	Burma (N)
Laos	Laos
India	Java

The effect of interaction between provenance and night temperature on the relative growth of root is depicted above. At 31°C, the differences among the provenances were not significant. However, at 22°C there were significant differences among some provenances (Figure 22.2). The relative growth of root for the Indian provenance was significantly higher than for

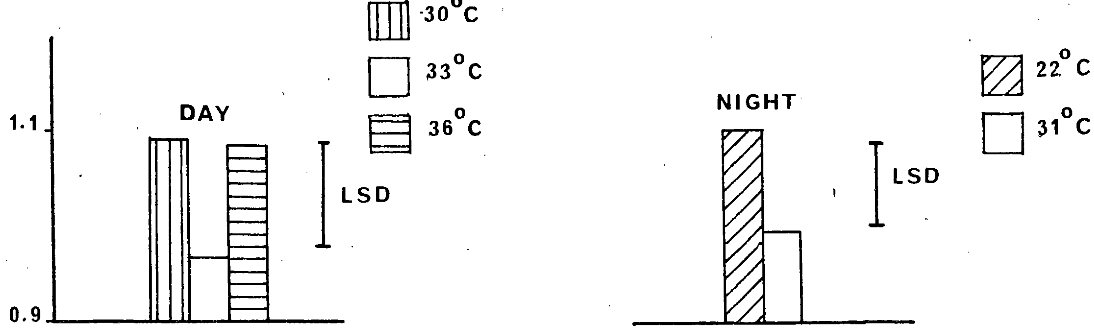


Figure 22.1 The relative growth of shoot to root at 30°C, 33°C and 36°C day temperatures and 22°C and 30°C night temperatures.

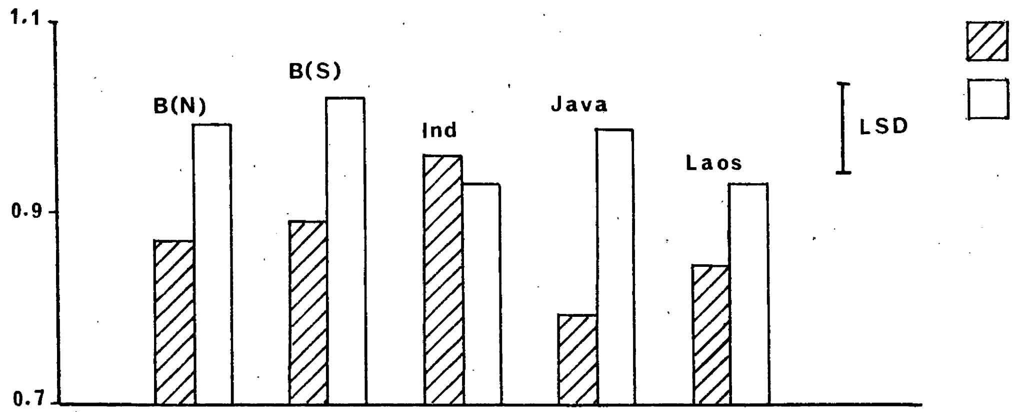


Figure 22.2 The relative growth of root weight to total weight of the provenances studied at 22°C and 31°C night temperatures.

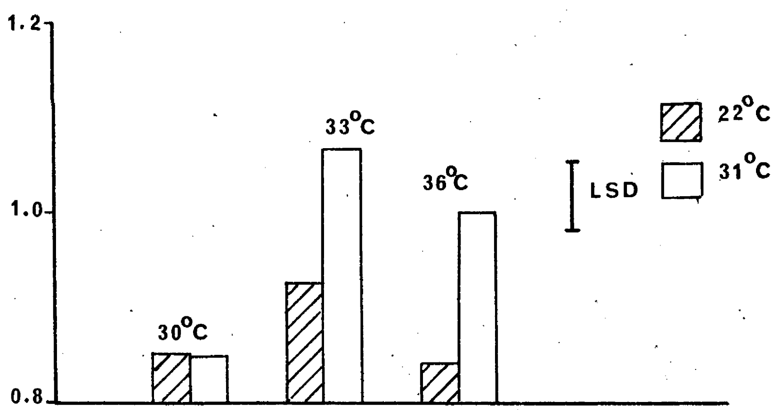


Figure 22.3 The relative growth of root weight to total weight at 30°C, 33°C and 36°C day temperatures and 22°C and 31°C night temperatures.

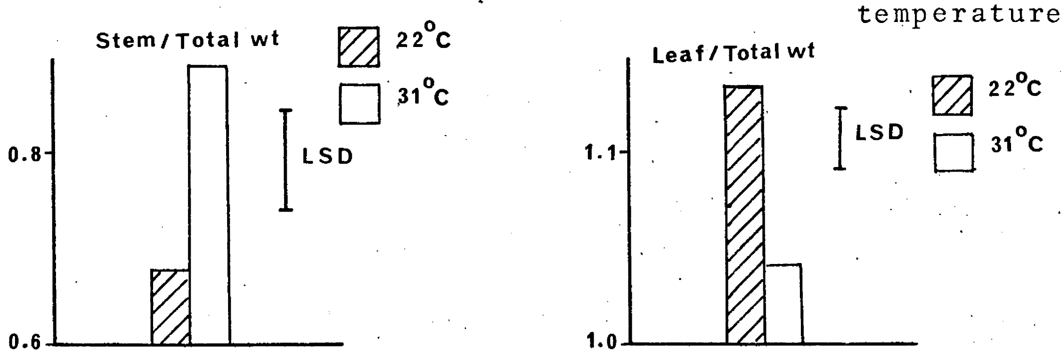


Figure 22.4 The relative growth of stem and leaf to total weight at 22°C and 31°C night temperatures.

the Laotian and Javanese provenances, whereas Burma (S) had a significantly higher relative growth of root than the Javanese provenance.

(iii) Relative growth of stem weight to total weight. The relative growth of stem to total weight was affected only by night temperatures (Figure 22.4). No significant differences were shown in the relative stem growth between the provenances or the three day temperatures studied.

The relative growth of stem was significantly greater at 31°C (0.892) than at 22°C (0.678) night temperatures, indicating more photosynthate was distributed towards the stem at the higher than at the lower night temperatures.

(iv) Relative growth of leaf weight to total weight. The relative growth of leaf to total weight was also affected significantly only by night temperature (Figure 22.4). The differences among the provenances and day temperatures studied were not significant (Table 46).

The relative growth of leaf to total weight was significantly higher at the lower night temperatures (1.135) than at the higher one (1.041). This indicated that less photosynthate was distributed towards the leaves at higher than at lower night temperatures studied within the range 22°C - 31°C.

15.4 Discussion and conclusion

15.4.1 Provenance.

Among the provenances studied, Northern Burmese provenance can be considered as the best and Indian provenance the poorest. The remaining three provenances varied in performance according to the prevailing day and night temperatures.

Northern Burmese provenance was always amongst the best in diameter and height growth and in leaf area ratio. The Indian provenance on the other hand was almost always amongst the poorest provenances. The Javanese provenance performed well at 36°C and 33°C day and 31°C night temperatures whilst Southern Burmese provenance preferred the other extreme of the temperature studied (33°C and 30°C day and 22°C night temperatures). The Laotian provenance showed very good performance in all three day temperatures and 31°C night temperature, but did not perform as well at 22°C night temperature.

There is therefore clear evidence of provenance variation, but no clear pattern on which to base recommendation. The Northern Burmese provenance can be selected for use over a wide temperature range including high temperatures. Most of the other provenances tested came from more tropical and therefore warmer locations, and they appear to be adapted to narrower temperature limits. Further study of provenance variation and the effect of temperature is needed.

15.4.2 Growth

The growth parameters studied generally show to advantage at both higher day and night temperatures within the range studied. The only exception was LAR which demonstrated the reverse effect.

(i) Day temperature. The growth parameters studied, namely, diameter growth, height growth, and NAR increased with the increase in day temperature from 30°C to 36°C, indicating the preference of the species for higher temperature. LAR however decreased with increase in day temperature. This could be due to the species having to adjust its internal water balance with the increased temperature.

(ii) Night temperature. The effect of night temperature on growth was more pronounced than that of day temperature. Diameter growth, height growth, RGR and LAR were higher at 31°C than at 22°C night temperatures. NAR was however not affected.

Due to the higher respiration and consequently the inefficient utilization of more photosynthate at higher night temperature, RGR was expected to be lower at the higher night temperature. The greater LAR recorded at the higher night temperature, however, must be allowing comparatively more photosynthate to be produced to compensate for the increased quantity used up in respiration. Thus, the improved RGR at the higher night temperature was mainly due to the greater LAR at that temperature. This suggests some studies of leaf structure and development in teak at high temperatures would be valuable.

It is clear that teak seedlings thrive at high day and night temperatures, but there must be an upper limit above which growth will decline. This needs further study. However, 36°C is quite high by the standard of other species. Cremer (1968) found the optimum temperature for *Pinus radiata* to be 24°/19°C under the phytotron condition whilst Slee (personal communication) found the phytotron optimum for a tropical pine (*Pinus caribaea*) to be 27°/22°C.

Although the stem growth (diameter and height growth) was still responding to the increase in day temperature from 30°-36°C the fact that the RGR did not respond to day temperature suggests that the upper limit of temperature range for good development of teak seedlings could be within the vicinity of the temperature range studied. 36°/31°C may therefore be approaching the maximum desirable temperature limit for teak.

15.4.3 Dry matter distribution

(i) Day temperature. Only the relative growth of shoot to root and that of root weight to total weight were affected by day temperature. The relative growth of shoot to root was poorest at 33°C with no significant difference shown between 30°C and 36°C. The relative growth of root weight to total weight correspondingly was best at 33°C. Since the relative growth of shoot (i.e. leaf and stem) was not affected by day temperature, clearly the drop in relative growth of shoot to root was solely due to more photosynthate being distributed towards the root (as shown by the increase in relative growth of root) at that particular temperature.

Therefore, since the distribution of dry matter towards the root increased as the day temperature was increased from 30°C to 33°C, and decreased again with further increase in temperature from 33°C to 36°C, it appears that 33°C may be a critical or near critical point at the higher day temperature limit of the species, at which the plant starts to readjust its development processes for survival at higher temperature. This strengthens the possibility that the temperature regimes studied could be approaching the vicinity of the upper limit of the temperature range for good development of teak seedlings as discussed above.

(ii) Night temperature. Night temperature showed a significant effect on the distribution of dry matter on all parts of the plant. More photosynthate was distributed towards the stem and root, and less towards the leaves at 31°C than at 22°C night temperature. Thus, although the leaf area ratio was higher at higher night temperature (see 15.4.2(ii)), photosynthate distributed towards the leaves was less. This also suggests a change in leaf structure with temperature. From the production point of view, it is preferable to have more photosynthate distributed towards the stem and in the seedling stage, good root development is preferable for good stump production. Thus, higher night temperatures appear generally desirable for teak up to at least 31°C.

In conclusion, the Northern Burmese provenance can be considered the best and the Indian provenance the poorest within the range studied. The Javanese provenance performed well at the higher day and night temperatures while the Southern Burmese provenance preferred the other extreme of the temperature range. The Laotian provenance performed well in all the temperature regimes studied except at the lower night temperature (22°C).

Growth and development of teak was better at both the higher day and night temperature regimes examined. The effect of night temperature on the relative growth rate was significant, due mainly to the increase in leaf area ratio with night temperature.

CHAPTER XVI

CONCLUSION

The importance of teak in South East Asia is indisputable, and the need is evident for establishment of high quality teak plantation, even in Burma, the leading teak exporting country in the world.

16.1 Occurrence

Teak occurs naturally only in India, Burma, Thailand and Laos. The occurrence in Indonesia is not natural. It was introduced in the seventh century and would therefore be sufficiently modified and adapted to that locality so as to be considered as a separate provenance.

Within its natural range, teak occurs only in semi-evergreen, moist upper mixed deciduous, lower mixed deciduous, dry upper mixed deciduous and indaing forest types according to the standard of classification. However, for plantation establishment, the order of preference would be:

(i) Moist upper mixed deciduous

(ii) Lower mixed deciduous

(iii) Semi-evergreen

(iv) Dry upper mixed deciduous

Indaing forest type is not suitable for establishment of teak plantation.

16.2 Requirements of the species

16.2.1 Rainfall

Teak grows best within the rainfall range between 1300 -

3800 mm but still occurs within the extreme limits of 760 - 5,080 mm. The species cannot tolerate inundation nor severe drought, but needs at least two months of definite dry season for normal development.

16.2.2 Temperature

Teak has been recorded as growing well in shade temperatures ranging between 12.5°C - 40°C. Experiments carried out using seedling in the controlled environments with a five degree difference in day and night temperatures demonstrated very poor development at 15°/10°C (day/night), but the species grew well in temperatures of 21°/16°C and higher. Within the temperature range studied (15°/10°C - 36°/31°C), teak grew best between 27°/22°C and 36°/31°C. Performance at higher temperature regimes was not studied.

A more precise experiment at higher temperature showed development and growth of teak was better at higher than at lower day temperatures within the range 30°C - 36°C. Growth analysis showed this to be due to an increase in net assimilation rate with an increase in day temperature.

The effect of night temperature on the development of teak was more pronounced than that of day temperature. The better growth at the 31°C than at the 22°C night temperature was due to a higher leaf area ratio at 31°C.

Studies of photosynthate distribution within teak seedlings showed the concentration of photosynthate towards the stem increased with temperature as the regimes varied from 18°/13°C to 27°/22°C. Similarly photosynthate was also found to be concentrated more towards the stem at 31°C than at 22°C night temperatures. No difference was found with day temperatures within the range 30°C - 36°C.

Thus, for good development of teak it is preferable to have high temperatures. Although high day temperatures (up to 36°C) are useful, high night temperatures up to at least 31°C appear particularly desirable.

16.2.3 Light

Although teak is a strong light demander, it is reported as preferring slight shading during the seedling stage.

There was little effect of photoperiod in seedling development in controlled environment studies except at extremely short days. Growth of teak seedlings improved with the increase in photoperiod from 8 hours to 12 hours, but the species did not respond further with an increase from 12 hours to 16 hours. As with the temperature effect, the increase in photosynthate with the increase in photoperiod from 8 hours to 12 hours was directed more towards the stem than any other part of the plant.

In tropical areas therefore daylength fluctuations appear unlikely to affect growth appreciably.

16.2.4 Soils

Review of the literature indicates soil type as an important factor in the establishment of teak plantation. Generally, teak prefers soil of good structure such as deep, well drained sandy loam soil. The species cannot tolerate stiff clayey or lateritic soil.

16.3 Germination

Germination of teak is generally poor and sporadic. Deficiencies in germination are further aggravated if seeds are collected early in the season, as they contain a higher percentage of damaged and imiture seed than those collected later in the season.

Normally, it is better to pretreat the seed before germination. Experiments showed the common practice of alternate soaking in water and drying to be the most suitable. However, this process does not give entirely satisfactory results although germination increased as the period of pretreatment increased from one week to three weeks. The optimum period of treatment may be longer than this and still needs to be determined. The major problem of obtaining satisfactory germination in teak still remains.

16.4 Nursery and establishment techniques

A review has clearly indicated that the use of a temporary nursery should be preferred where scattered small areas are to be established. However, for an extensive area of plantation, a semi-permanent nursery with a life of six years would be most suitable. Present knowledge probably limits the safe use of a nursery site to a maximum of seven years. To assist in maintaining soil fertility, nursery areas should be used in rotation.

Seedlings can be lifted and converted to stumps one year after sowing. One to two centimetres diameter at the collar is the best size for making stumps. For good survival in the field, stumps should not be stored or transported for more than two weeks.

Establishment by the taungya method is the most suitable where there is a population pressure and the demand for land is high. Where this method is impracticable, mechanization should be considered.

Although teak is a very hardy species, it is difficult to manage silviculturally. Wide initial spacing is not desirable as it would promote production of both a large non-durable central core and coasre branching. For good development, production of quality timber and adequate weed control, a 1.8 x 1.8m initial spacing appears to be best. At a later age however, the presence of undergrowth to act as ground cover to prevent serious erosion is desirable. This requires manipulation of the crown spacing to allow enough light to encourage the development of undergrowth. At the same time the gaps produced cannot be so large so as to induce heavy branching. Thus, a frequent and regular thinning is necessary in a teak plantation.

Neglect of thinning besides leading to severe erosion also checks the species development so severely that recovery could be difficult.

16.5 Variation

There is clear evidence, in the literature, of provenance variation in teak. Studies of variation in germination suggested the Southern Burmese provenance was superior in germination to the Northern Burmese provenance. Variation in germination also appeared to exist between the Indian, Javanese and Laotion provenance, but a definite conclusion could not be drawn as information on seed collection and storage was not available.

A study of variation in seedling development in controlled environments indicated the Northern Burmese provenance was generally the best and the Indian provenance the poorest.

The Javanese provenance performed better at the higher day and night temperatures whilst the Southern Burmese provenance preferred the lower day and night temperatures. The Laotian provenance did not show any difference within the day temperature regimes studied (30°C-36°C), but showed preference for higher night temperature.

Thus, the Northern Burmese provenance could be used with some confidence in any area suitable for teak growth. The Javanese and the Laotian provenances appear most suited to tropical areas where day and night temperatures are high, whilst the Southern Burmese provenance might be best in less tropical, cooler areas. The Indian provenance should be used only when seeds from other provenances are unavailable or when experiments have indicated its usefulness in the locality.

16.6 Possibilities for tree breeding

As well as the more usual tree breeding criteria, late flowering appeared important in teak. This is because a fork develops after the initial flowering in teak. Propagation of strains with desirable characteristics is most easily effected vegetatively by means of budding. Therefore, as the species can be easily propagated vegetatively, and because late flowering is a desirable characteristic, clonal seed orchards would be more suitable than seedling seed orchards.

It is very inconvenient to carry out control pollinations in teak and open pollinated tests appear more suitable in many ways. However, if control-pollinations are desired, isolation and emasculation must be carried out within one hour of the flowers becoming fully opened, and the best time to carry out pollinations is between 10 a.m. and 3 p.m.

APPENDIX I

List of species commonly found in the various forest types of Burma

Burmese Name	Botanical Name
Tropical Wet Evergreen	
Tree Species	
Aukchinsa	Diospyros ehretioides Wall
Gangaw	Mesua ferrea Linn.
Kanaso	Baccaurea sapida Muell.
Kanyin	Dipterocarpus spp.
Karawe	Cinnamomum inunctum Meissn.
Kaunghmu	Anisoptera scaphula (Roxb.) Pierre
Kyilan	Shorea assamica Dyer.
Myauklok	Artocarpus lakoocha Roxb.
Sagawa	Michelia champaca Linn.
Taungpein	Artocarpus calophylla Kurz.
Taungthayet	Swintonia floribunda Griff.
Tawthayet	Mangifera caloneura Kurz.
Thabyegyi	Eugenia grandis Wight.
Thingadu	Parashorea stellata Kurz.
Thingan	Hopea odorata Roxb.
Thitka	Pentace burmanica Kurz.
Thitsho	Pentace griffithii King
Yinma	Chukrasia tabularis A. Juss.
Bamboos	
Tinwa	Cephalostachyum pergracile Munro
Wabo or Kyalo	Dendrocalamus brandisii Kurz.
Wabomyetsangye	Dendrocalamus hamiltonii Nees. ex Arn.
Wanwe	Oxytenanthera albo-ciliata Munro
Wapyugyi	Gigantochloa macrostachaya Kurz.
Wathabut	Bambusa marginata Munro
Tropical Semi-Evergreen	
Tree Species	
Baing	Tetrameles nudiflora R. Br.
Bambwe	Careya arborea Roxb.
Didu	Salmalia insignis Schott and Endl.
Gwe	Spondias pinnata (Linn.) Kurz.
Gyo	Schleichera oleosa (Lour.) Merr.
Kalaw	Hydnocarpus kurzii (King) Warburg
Kanyin	Dipterocarpus spp.
Letkok	Pterygota alata (Roxb.) R. Br.
Letpan	Salmalia malabarica Schott and Endl.
Myaukchaw	Homalium tomentosum Benth.

APPENDIX I (cont'd)

List of species commonly found in the various forest types of Burma

Burmese Name	Botanical Name
Pyinkado	Xylia dolabriformis Benth.
Pyinma	Lagerstroemia speciosa (Linn.) Pers.
Sit	Albizzia procera Benth.
Taukkyan	Terminalia tomentosa W. and A.
Taungpeinne	Artocarpus chaplasha Roxb.
Teak or Kyun	Tectona grandis Linn. f.
Thabaung	Calamus longisetus Griff.
Thabye	Eugenia spp.
Yemane	Gmelina arborea Roxb.
Bamboos	
Kyathaungwa	Bambusa polymorpha Munro
Tinwa	Cephalostachyum pergracile Munro
Wabomyetsangye	Dendrocalamus hamiltonii Nees and Arn.
Wapyu	Dendrocalamus membranaceus Munro
	Moist Upper Mixed Deciduous
Tree Species	
Binga	Mitragyna rotundifolia O. Ktze.
Didu	Salmalia insignis Schott and Endl.
Myaukchaw	Homalium tomentosum Benth.
Nabe	Lannea grandis Eng.
Padauk	Pterocarpus macrocarpus Kurz.
Pyinkado	Xylia dolabriformis Benth.
Pyinma	Lagerstroemia speciosa Pers.
Teak or Kyun	Tectona grandis Linn. f.
Yemane	Gmelina arborea Roxb.
Bamboos	
Kyathaungwa	Bambusa polymorpha Munro
Tinwa	Cephalostachyum pergracile Munro
Wabomyetsangye	Dendrocalamus hamiltonii Nees ex Arn.
	Dry Upper Mixed Deciduous
Tree Species	
Hnaw	Adina cordifolia Hook. f.
In	Dipterocarpus tuberculatus Roxb.
Ingyin	Pentacme siamensis (Miq.) Kurz.
Lein	Terminalia pyrifolia Kurz.
Padauk	Pterocarpus macrocarpus Kurz.

APPENDIX I (cont'd)

List of species commonly found in the various forest types of Burma

Burmese Name	Botanical Name
Panga	Terminalia chebula Retz.
Pyinkado	Xylia dolabriformis Benth.
Taukkyan	Terminalia tomentosa W. and A.
Teak or Kyun	Tectona grandis Linn. f.
Thitya	Shorea oblongifolia Thw.
Bamboos	
Kyathaungwa	Bambusa polymorpha Munro
Thaikwa	Bambusa tulda Roxb.
Thanawa	Thyrsostachys oliveri Gamble
Tinwa	Cephalostachyum pergracile Munro
Myinwa	Dendrocalamus strictus Nees.
	Lower Mixed Deciduous
Tree Species	
Leza	Lagerstroemia tomentosa Presl.
Myaukchaw	Homalium tomentosum Benth.
Pyinkado	Xylia dolabriformis Benth.
Pyinma	Lagerstroemia speciosa (Linn.) Pers.
Sit	Albizzia procera Benth.
Taukkyan	Terminalia tomentosa W. and A.
Teak or Kyun	Tectona grandis Linn. f.
Yon	Anogeissus acuminata Wall.
Zinbyun	Dillenia pentagyna Roxb.
	Deciduous Dipterocarp or Indaing Forests
Tree Species	
In	Dipterocarpus tuberculatus Roxb.
Ingyin	Pentacme siamensis (Miq.) Kurz.
Thitsi	Melanorrhoe usitata Wall.
Thitya	Shorea oblongifolia Thw.
	Dry Forests
Tree Species	
Dahat	Tectona hamiltoniana Wall.
Sha	Acacia catechu Willd.
Tanaung	Acacia leucophloea Willd.
Te	Diospyros burmanica Kurz.
Than	Terminalia oliveri Brandis

APPENDIX I (cont'd)

List of species commonly found in the various forest types of Burma

Burmese Name	Botanical Name
Bamboos	
Myinwa	Dendrocalamus strictus Nees.
	Hill Forests
Tree Species	
Laukya	Schima wallichii Choisy
Maibau	Alnus nepalensis Don.
Thitcha	Castanopsis spp.
Thite	Quercus spp.
Tinshu	Pinus merkusii Jungh.
Tinshu	Pinus kesiya Royle ex Gordon
	Tidal Forest
Tree species	
Baingdaung	Ceriops roxburghiana Arn.
Byu	Rhizophora mucronata Lam.
Hnit	Brugucera parviflora W. and A
Kanazo	Heritiera fomes Buch.
Kaya	Acanthus ilicifolius Linn.
Kyana	Xylocarpus moluccensis Lam.
Madama	Bruguiere caryophylloides Blume.
	Beach and Dunes Forests
Tree Species	
Kabwe	Casuarina equisetifolia Forst.
Kathit	Erythrina indica Lam.
Myatya	Grewia microcos Linn.
Ponnyet	Calophyllum inophyllum Linn.
Swedaw	Thespesia populnea Corr.
Thabye	Eugenia spp.
Thinwin-pyu	Pongarnia pinnata Linn.
	Swamp Forest
Tree Species	
Pyinma	Lagerstroemia speciosa (Linn.) Pers.
Tawthayet	Mangifera caloneura Kurz.
Thitni	Amoora cucullata Roxb.

APPENDIX II

List of forest divisions included in the proposed provenances.

in Burma

Northern Provenance

1. Myittha forest division
2. Upper Chindwin forest division
3. West Katha forest division
4. Myitkyina forest division

Southern Provenance

1. North Toungoo forest division
2. South Toungoo forest division
3. North Pegu forest division
4. South Pegu forest division
5. Paan forest division
6. Insein forest division
7. Tharawaddy forest division
8. Zigon forest division
9. Henzada/Bassein forest division

Eastern Provenance

1. Northern Shan State forest division
2. Southern Shan State forest division
3. Kayah forest division

APPENDIX II (cont.)

List of Forest Divisions included in the proposed provenances in Burma

Central Provenance

1. Shwebo forest division
2. East Katha forest division
3. Mongmit forest division
4. Mandalay/Maymyo forest division
5. Meiktila forest division
6. Yamethin forest division
7. Pyinmana forest division
8. Prome forest division
9. Thayetmyo forest division
10. Allanmyo forest division
11. Minbu forest division
12. Yaw forest division
13. Lower Chindwin forest division

Tenasserim Provenance

1. Thaton/Ataran/Kadoe and agency division

APPENDIX III

Composition of modified Hoagland Solution

$Ca(NO_3)_2.4H_2O$	95g/100L
$(NH_4)H_2PO_4$	6g/100L
KNO_3	61g/100L
$MgSO_4.7H_2O$	49g/100L
H_3BO_3	0.06g/100L
$MnCl_2.4H_2O$	0.04g/100L
$ZnSO_4.7H_2O$	0.009g/100L
$CuSO_4.5H_2O$	0.005g/100L
$H_2MoO_4.4H_2O$	0.002g/100L
$Co(NO_3)_2.6H_2O$	0.0025g/100L
$FeSO_4.7H_2O$	2.49g/100L
EDTA	3.32g/100L
NaOH	0.50g/100L

Source: Phytotron users guide (Anonymous, 1970b).

APPENDIX IV

Analyses of variance for photoperiod experiment

Source of variation	df.	Sum of squares	Mean squares	F
		Relative growth rate (1)		
Temperature	1	0.000159	0.000159	0.32
Photoperiod	2	0.000810	0.000406	0.81
Grade	4	0.004345	0.001086	2.17
Phot. x Temp.	2	0.000468	0.000234	0.47
Grade x Temp.	4	0.002922	0.000731	1.46
Grade x Photo.	8	0.015292	0.001912	3.82*
Error	8	0.004002	0.000500	
		Relative Growth rate (2)		
Temperature	1	0.000941	0.000941	1.88
Photoperiod	2	0.000523	0.000262	0.52
Grade	4	0.000487	0.000122	0.24
Photo x Temp	2	0.002007	0.001004	2.00
Grade x Temp.	4	0.002304	0.000576	1.15
Grade x Photo,	8	0.006415	0.000802	1.60
Error	8	0.004016	0.000502	
		Net assimilation rate(1)		
Temperature	1	0.094304	0.094304	7.31*
Photoperiod	2	0.032798	0.016399	1.27
Grade	4	0.078843	0.019711	1.53
Photo x Temp.	2	0.006215	0.003108	0.24
Grade x Temp.	4	0.093504	0.023376	1.81
Grade x Photo.	8	0.296015	0.037002	2.87
Error	8	0.103165	0.012896	
		Net assimilation rate (2)		
Temperature	1	0.005495	0.005495	0.65
Photoperiod	2	0.105337	0.052669	6.19
Grade	4	0.019834	0.004959	0.58
Photo x Temp.	2	0.062131	0.031066	3.65
Grade x Temp.	4	0.035641	0.008910	1.05
Grade x Photo.	8	0.126099	0.015762	1.85
Error	8	0.068091	0.008511	
		Leaf area ratio(1)		
Temperature	1	10087.0553	10087.0553	86.83**
Photoperiod	2	18623.2886	9311.6443	80.16**
Grade	4	67.5880	16.8970	0.15
Photo x Temp.	2	520.5610	260.2805	2.24
Grade x Temp.	4	418.9016	104.7254	0.90
Grade x Photo.	8	1215.2453	151.9057	1.31
Error	8	929.3642	116.1705	

APPENDIX IV cont'd...

Analyses of variance for photoperiod experiment

Source of variation	df.	Sum of squares	Mean squares	F
		Leaf area ratio (2)		
Temperature	1	9440.3623	9440.3623	27.98**
Photoperiod	2	17521.0191	8760.5096	25.96**
Grade	4	227.1087	56.7772	0.17
Photo. x temp.	2	1966.7003	983.3502	2.91
Grade x Temp.	4	423.3801	105.8450	0.31
Grade x Photo.	8	1034.0498	129.2562	0.38
Error	8	2699.6916	337.4615	
		Diameter increment		
Temperature	1	0.000018	0.000018	4.50
Photoperiod	2	0.000021	0.000011	2.75
Grade	4	0.000048	0.000012	3.00
Photo x temp.	2	0.000003	0.000002	0.50
Grade x temp.	4	0.000033	0.000008	2.00
Grade x photo.	8	0.000060	0.000008	2.00
Error	8	0.000033	0.000004	
		Relative diameter growth		
Temperature	1	0.000002	0.000002	0.08
Photoperiod	2	0.000168	0.000084	3.11
Grade	4	0.000138	0.000035	1.30
Photo x temp.	2	0.000026	0.000013	0.49
Grade x temp.	4	0.000159	0.000040	1.48
Grade x photo.	8	0.000129	0.000016	0.59
Error	8	0.000214	0.000027	
		Height increment		
Temperature	1	0.3645	0.3645	25.49**
Photoperiod	2	0.4243	0.2122	14.84**
Grade	4	0.1013	0.0253	1.77
Photo x temp.	2	0.0703	0.0352	2.46
Grade x temp.	4	0.0779	0.0195	1.36
Grade x photo.	8	0.1415	0.0177	1.24
Error	8	0.1147	0.0143	
		Relative height growth		
Temperature	1	0.000009	0.000009	0.38
Photoperiod	2	0.000030	0.000015	0.63
Grade	4	0.000578	0.000145	6.04*
Photo x temp.	2	0.000056	0.000028	1.17
Grade x temp.	4	0.000123	0.000031	1.29
Grade x photo.	8	0.000413	0.000052	2.16
Error	8	0.000188	0.000024	

APPENDIX IV cont'd...

Analyses of variance for photoperiod experiment

Source of variation	df.	Sum of squares	Mean squares	F
		Log_eshoot wt/$\log_e$root wt		
Temperature	1	0.000340	0.000340	0.21
Photoperiod	2	0.008090	0.004045	2.56
Grade	4	0.012812	0.003203	2.02
Photo x Temp.	2	0.003591	0.001796	1.13
Grade x Temp.	4	0.012601	0.003150	1.99
Grade x Photo.	8	0.008499	0.001062	0.67
Error	8	0.012667	0.001583	
		Log_eroot wt/$\log_e$total wt		
Temperature	1	0.000137	0.000137	0.36
Photoperiod	2	0.002242	0.001121	2.94
Grade	4	0.003232	0.000808	2.12
Photo x Temp.	2	0.001040	0.000520	1.36
Grade x Temp.	4	0.003321	0.000830	2.18
Grade x Photo.	8	0.002138	0.000267	0.70
Error	8	0.003051	0.000381	
		Log_estem wt/$\log_e$total wt		
Temperature	1	0.005109	0.005109	20.60**
Photoperiod	2	0.009681	0.004841	19.52**
Grade	4	0.000129	0.000032	0.13
Photo x Temp.	2	0.000187	0.000094	0.38
Grade x Temp.	4	0.000614	0.000154	0.62
Grade x Photo.	8	0.002561	0.000320	1.29
Error	8	0.001982	0.000248	
		Log_eleaf wt/$\log_e$total wt		
Temperature	1	0.000140	0.000140	2.86
Photoperiod	2	0.000165	0.000083	1.69
Grade	4	0.000296	0.000074	1.51
Photo x Temp.	2	0.000070	0.000035	0.71
Grade x Temp.	4	0.000151	0.000038	0.78
Grade x Photo.	8	0.000174	0.000022	0.45
Error	8	0.000394	0.000049	

APPENDIX V

Analysis of variance on germination of teak seed from five different provenances

Source of variation	df.	Sum of squares	Mean squares	F
		Peak value		
Provenance	4	167.3166	41.8292	114.51**
Error	95	34.7056	0.3653	
		Mean daily germination		
Provenance	4	1.3375	0.3344	4.00**
Error	95	7.9426	0.0836	
		Germination value		
Provenance	4	473.4176	118.3544	84.08**
Error	95	133.7181	1.4076	

APPENDIX VI

Detailed results of the provenance experiment

Provenance	Temp.	30°C	33°C	36°C	Night temp. mean	Provenance mean
		(i) Diameter increment (cm/day)				
Burma (N)	31°C	0.0114	0.0136	0.0176	0.0142	
	22°C	0.0088	0.0091	0.0140	0.0106	
	Mean	0.0101	0.0114	0.0158		0.0124
Burma (S)	31°C	0.0104	0.0131	0.0142	0.0126	
	22°C	0.0073	0.0122	0.0120	0.0105	
	Mean	0.0089	0.0127	0.0131		0.0116
India	31°C	0.0080	0.0102	0.0142	0.0108	
	22°C	0.0055	0.0066	0.0090	0.0070	
	Mean	0.0068	0.0084	0.0116		0.0089
Java	31°C	0.0100	0.0149	0.0178	0.0142	
	22°C	0.0053	0.0098	0.0126	0.0092	
	Mean	0.0077	0.0124	0.0152		0.0117
Laos	31°C	0.0111	0.0134	0.0184	0.0143	
	22°C	0.0075	0.0081	0.0119	0.0092	
	Mean	0.0093	0.0108	0.0152		0.0118
Day Temp. Mean	31°C	0.0102	0.0130	0.0164		
	22°C	0.0069	0.0092	0.0119		
	Mean	0.0086	0.0111	0.0142		
Night Temp. Mean	31°C				0.0132	
	22°				0.0093	
		(ii) Relative diameter increment (cm/cm/day)				
Burma (N)	31°C	0.0285	0.0329	0.0349	0.0321	
	22°C	0.0258	0.0289	0.0475	0.0341	
	Mean	0.0272	0.0309	0.0412		0.0331
Burma (S)	31°C	0.0328	0.0336	0.0364	0.0343	
	22°C	0.0231	0.0390	0.0405	0.0342	
	Mean	0.0280	0.0363	0.0385		0.0343

APPENDIX VI cont'd...

Detailed results of the provenance experiment

Provenance	Temp.	30°C	33°C	36°C	Night temp. mean	Provenance mean
India	31°C	0.0248	0.0261	0.0345	0.0285	
	22°C	0.0165	0.0213	0.0358	0.0245	
	Mean	0.0207	0.0237	0.0352		0.0265
Java	31°C	0.0288	0.0384	0.0424	0.0365	
	22°C	0.0196	0.0291	0.0419	0.0302	
	Mean	0.0242	0.0338	0.0422		0.0334
Laos	31°C	0.0339	0.0325	0.0394	0.0353	
	22°C	0.0314	0.0222	0.0366	0.0301	
	Mean	0.0327	0.0274	0.0380		0.0327
Day Temp. Mean	31°C	0.0298	0.0327	0.0375		
	22°C	0.0233	0.0281	0.0405		
	Mean	0.0266	0.0304	0.0390		
Night Temp. Mean	31°C				0.0333	
	22°C				0.0306	

(iii) Height increment (cm/day)

Provenance	Temp.	30°C	33°C	36°C	Night temp. mean	Provenance mean
Burma (N)	31°C	0.4542	0.3333	0.5710	0.4528	
	22°C	0.2050	0.1397	0.1700	0.1716	
	Mean	0.3296	0.2365	0.3705		0.3122
Burma (S)	31°C	0.2956	0.3267	0.4500	0.3574	
	22°C	0.1025	0.1244	0.1240	0.1170	
	Mean	0.1991	0.2256	0.2870		0.2372
India	31°C	0.2692	0.3533	0.4160	0.3462	
	22°C	0.1425	0.1625	0.1067	0.1372	
	Mean	0.2059	0.2579	0.2614		0.2417
Java	31°C	0.3600	0.4133	0.3800	0.3844	
	22°C	0.0925	0.1489	0.0980	0.1131	
	Mean	0.2263	0.2811	0.2390		0.2488
Laos	31°C	0.3000	0.3219	0.6022	0.4080	
	22°C	0.0500	0.1337	0.0963	0.0933	
	Mean	0.1750	0.2278	0.3493		0.2507

APPENDIX VI cont'd..

Detailed results of the provenance experiment

Provenance	Temp.	30°c	33°C	36°C	Night Temp. mean	Provenance mean
Day	31°C	0.3358	0.3497	0.4838		
Temp.	22°C	0.1185	0.1418	0.1190		
Mean	Mean	0.2272	0.2458	0.3014		
Night	31°C				0.3898	
temp.	22°C				0.1264	
Mean						
		(iv) Relative height growth (cm/cm/day)				
	31°C	0.0161	0.0511	0.0563	0.0563	
Burma (N)	22°C	0.0366	0.0298	0.0449	0.0371	
	Mean	0.0491	0.0405	0.0506		0.0467
	31°C	0.0579	0.0512	0.0584	0.0058	
Burma (S)	22°C	0.0272	0.0374	0.0383	0.0343	
	Mean	0.0426	0.0443	0.0484		0.0451
	31°C	0.0434	0.0476	0.0447	0.0452	
India	22°C	0.0293	0.0345	0.0351	0.0330	
	Mean	0.0364	0.0411	0.0399		0.0391
	31°C	0.0652	0.0658	0.0632	0.0647	
Java	22°C	0.0305	0.0437	0.0333	0.0358	
	Mean	0.0479	0.0548	0.0483		0.0503
	31°C	0.0596	0.0443	0.0669	0.0569	
Laos	22°C	0.0193	0.0260	0.0258	0.0237	
	Mean	0.0395	0.0352	0.0464		0.0403
Day	31°C	0.0575	0.0520	0.0579		
Temp.	22°C	0.0286	0.0343	0.0355		
Mean	Mean	0.0431	0.0432	0.0467		
Night	31°C				0.0558	
temp.	22°C				0.0328	
Mean						
		(v) Relative growth rate (g/g/day)				
	31°C	0.1158	0.0945	0.1321	0.1141	
Burma (N)	22°C	0.0982	0.0860	0.1095	0.0979	
	Mean	0.1070	0.0903	0.1208		0.1060

APPENDIX VI cont'd...

Detailed results of the provenance experiment

Provenance	Temp.	30°C	33°C	36°C	Night temp. mean	Provenance mean
Burma (S)	31°C	0.1043	0.1378	0.1206	0.1209	
	22°C	0.0928	0.0881	0.0769	0.0859	
	Mean	0.0986	0.1130	0.0988		0.1034
India	31°C	0.0977	0.0934	0.1038	0.0983	
	22°C	0.0923	0.0734	0.0863	0.0840	
	Mean	0.0950	0.0834	0.0951		0.0912
Java	31°C	0.1264	0.1317	0.1198	0.1260	
	22°C	0.0840	0.1164	0.0907	0.0970	
	Mean	0.1052	0.1241	0.1053		0.1115
Laos	31°C	0.1356	0.1173	0.1216	0.1248	
	22°C	0.0249	0.0774	0.1222	0.0748	
	Mean	0.0803	0.0974	0.1219		0.0998
Day Temp. Mean	31°C	0.1160	0.1149	0.1196		
	22°C	0.0784	0.0883	0.0971		
	Mean	0.0972	0.1016	0.1084		
Night Temp. Mean	31°C				0.1168	
	22°C				0.0879	

(vi) Net assimilation rate (mg/cm^2/day)

Provenance	Temp.	30°C	33°C	36°C	Night temp. mean	Provenance mean
Burma (N)	31°C	0.4185	0.3689	0.6468	0.4781	
	22°C	0.4525	0.4196	0.7217	0.5313	
	Mean	0.4355	0.3943	0.6843		0.5047
Burma (S)	31°C	0.3885	0.5412	0.5486	0.4928	
	22°C	0.4917	0.4682	0.4821	0.4810	
	Mean	0.4401	0.5047	0.5159		0.4869
India	31°C	0.4032	0.4314	0.5893	0.4746	
	22°C	0.5090	0.4567	0.6545	0.5401	
	Mean	0.4561	0.4441	0.6219		0.5074
Java	31°C	0.4648	0.5174	0.5207	0.5010	
	22°C	0.4169	0.6122	0.5652	0.5314	
	Mean	0.4409	0.5648	0.5430		0.5162

APPENDIX VI cont'd...

Detailed results of the provenance experiment

Provenance	Temp.	30°C	33°C	36°C	Night temp. mean	Provenance mean
Laos	31°C	0.4448	0.4463	0.5587	0.4833	
	22°C	0.1330	0.3855	0.7688	0.4291	
	Mean	0.2889	0.4159	0.6638		0.4562
Day Temp. Mean	31°C	0.4240	0.4610	0.5728		
	22°C	0.4006	0.4684	0.6387		
	Mean	0.4123	0.4647	0.6058		
Night Temp. Mean	31°C				0.4860	
	22°C				0.5026	
	(vii) Leaf area ratio (1) (cm^2/gm)					
Burma (N)	31°C	254.10	257.45	186.73	232.76	
	22°C	201.11	190.91	155.96	182.66	
	Mean	227.61	224.18	171.35		207.71
Burma (S)	31°C	233.53	230.03	218.33	227.30	
	22°C	169.28	177.22	155.56	167.35	
	Mean	201.41	203.63	186.95		197.33
India	31°C	225.21	202.06	159.72	195.66	
	22°C	197.35	152.38	120.01	156.58	
	Mean	211.28	177.22	139.87		176.12
Java	31°C	249.66	260.48	230.80	246.98	
	22°C	197.58	156.44	146.00	166.67	
	Mean	223.62	208.46	188.40		206.83
Laos	31°C	277.23	241.95	194.95	283.04	
	22°C	212.60	197.66	150.31	186.86	
	Mean	244.92	219.81	172.63		212.45
Day Temp. Mean	31°C	247.95	238.39	198.11		
	22°C	195.58	174.92	145.57		
	Mean	221.77	206.66	171.84		
Night Temp. Mean	31°C				228.15	
	22°C				172.02	

APPENDIX VI cont'd ..

Detailed results of the provenance experiment

Provenance	Temp.	30°C	33°C	36°C	Night temp. mean	Provenance mean
	(viii) Leaf area ratio (2) (cm^2/gm)					
	31°C	291.25	255.18	219.76	255.40	
Burma (N)	22°C	238.04	218.67	149.20	201.97	
	Mean	264.65	236.93	184.48		228.68
	31°C	295.52	269.44	222.26	262.41	
Burma (S)	22°C	198.38	194.84	161.71	184.98	
	Mean	246.95	232.14	191.99		223.69
	31°C	254.87	227.69	183.78	222.11	
India	22°C	174.24	175.28	145.85	165.12	
	Mean	214.56	201.49	164.82		193.62
	31°C	286.27	251.90	230.03	256.07	
Java	22°C	203.50	214.59	172.42	196.84	
	Mean	244.89	233.25	201.23		226.45
	31°C	320.47	280.51	233.18	278.05	
Laos	22°C	166.67	208.93	169.28	181.63	
	Mean	243.57	244.72	201.23		229.84
Day	31°C	289.68	256.94	217.80		
Temp.	22°C	196.17	202.46	159.69		
Mean	Mean	242.92	229.70	188.75		
Night Temp.	31°C				254.81	
Mean	22°C				186.11	
	(ix) $\log_e$shoot wt/$\log_e$root wt					
	31°C	1.0575	0.9672	0.9600	0.9949	
Burma (N)	22°C	1.0569	0.9873	1.2923	1.1122	
	Mean	1.0572	0.9773	1.1262		1.0536
	31°C	0.9069	0.8401	0.9392	0.8954	
Burma (S)	22°C	1.1244	0.9428	1.1397	1.0690	
	Mean	1.0157	0.8915	1.0395		0.9822

APPENDIX VI cont'd...

Detailed results of the provenance experiment

Provenance	Temp.	30°C	33°C	36°C	Night temp. mean	Provenance mean
	31°C	1.0670	0.9474	1.0542	1.0229	
India	22°C	0.9945	1.0196	0.9651	0.9931	
	Mean	1.0308	0.9835	1.0097		1.0080
	31°C	1.1552	0.8848	0.9288	0.9896	
Java	22°C	1.1414	1.2187	1.2384	1.1995	
	Mean	1.1483	1.0518	1.0836		1.0946
	31°C	1.2789	0.9134	1.0211	1.0711	
Laos	22°C	1.1440	0.9461	1.2918	1.1273	
	Mean	1.2115	0.9298	1.1565		1.0992
Day	31°C	1.0931	0.9106	0.9807		
Temp.	22°C	1.0922	1.0229	1.1855		
Mean	Mean	1.0927	0.9668	1.0831		
Night	31°C				0.9948	
Temp.						
Mean	22°C				1.1002	

(x) $\log_e$root wt/$\log_e$total wt

Provenance	Temp.	30°C	33°C	36°C	Night temp. mean	Provenance mean
	31°C	0.9428	1.0098	1.0222	0.9916	
Burma (N)	22°C	0.9365	0.8831	0.7978	0.8725	
	Mean	0.9397	0.9465	0.9100		0.9321
	31°C	0.8187	1.1934	1.0463	1.0195	
Burma (S)	22°C	0.8451	1.0007	0.8337	0.8932	
	Mean	0.8319	1.0971	0.9400		0.9564
	31°C	0.8647	1.0063	0.9200	0.9303	
India	22°C	0.9730	0.9219	0.9803	0.9584	
	Mean	0.9189	0.9641	0.9502		0.9444
	31°C	0.8209	1.0885	1.0487	0.9860	
Java	22°C	0.7631	0.8138	0.8083	0.7951	
	Mean	0.7920	0.9512	0.9285		0.8906
	31°C	0.7977	1.0396	0.9562	0.9312	
Laos	22°C	0.7393	1.0071	0.7824	0.8429	
	Mean	0.7685	1.0234	0.8693		0.8871

APPENDIX VI cont'd...

Detailed results of the provenance experiment

Provenance	Temp.	30°C	33°C	36°C	Night Temp. mean	Provenance mean
Day	31°C	0.8490	1.0675	0.9987		
Temp.	22°C	0.8514	0.9253	0.8405		
Mean	Mean	0.8502	0.9964	0.9196		
Night	31°C				0.9717	
Temp.						
Mean	22°C				0.8724	
	(xi)	Log_estem wt/log_etotal wt				
	31°C	0.9806	1.0613	0.6351	0.8923	
Burma (N)	22°C	0.7561	0.8071	0.7539	0.7724	
	Mean	0.8684	0.9342	0.6945		0.8324
	31°C	0.8356	0.7667	0.9828	0.8617	
Burma (S)	22°C	0.6317	0.6959	0.6396	0.6557	
	Mean	0.7337	0.7313	0.8112		0.7587
	31°C	0.9127	0.9653	1.0458	0.9746	
India	22°C	0.8530	0.8221	0.7689	0.8147	
	Mean	0.8829	0.8937	0.9074		0.8947
	31°C	0.8350	0.8384	0.9979	0.8904	
Java	22°C	0.4753	0.7290	0.6375	0.6139	
	Mean	0.6552	0.7837	0.8177		0.7522
	31°C	0.7636	0.7707	0.9894	0.8412	
Laos	22°C	0.2295	0.7173	0.6571	0.5346	
	Mean	0.4966	0.7440	0.8233		0.6879
Day	31°C	0.8655	0.8805	0.9302		
Temp.	22°C	0.5891	0.7543	0.6914		
Mean	Mean	0.7273	0.8174	0.8108		
Night	31°C				0.8920	
Temp.						
Mean	22°C				0.6783	

APPENDIX VI cont'd...

Detailed results of the provenance experiment

Provenance	Temp.	30°C	33°C	36°C	Night Temp. mean	Provenance mean
	(xii) $\log_e$ leaf wt/$\log_e$ total wt					
Burma (N)	31°C	1.0153	0.9763	0.9976	0.9964	
	22°C	1.0886	1.0963	1.1256	1.1035	
	Mean	1.0520	1.0363	1.0616		1.0500
Burma (S)	31°C	1.1296	1.0417	0.9988	1.0567	
	22°C	1.1173	1.0901	1.1441	1.1172	
	Mean	1.1235	1.0659	1.0715		1.0870
India	31°C	1.0468	1.1748	0.9986	1.0734	
	22°C	1.0557	1.0798	1.0755	1.0703	
	Mean	1.0513	1.1273	1.0371		1.0719
Java	31°C	1.0709	1.0228	0.9938	1.0292	
	22°C	1.1813	1.1206	1.1399	1.1473	
	Mean	1.1261	1.0717	1.0669		1.0883
Laos	31°C	1.0856	1.0474	1.0092	1.0474	
	22°C	1.5068	1.0658	1.1363	1.2363	
	Mean	1.2962	1.0566	1.0728		1.1419
Day Temp. Mean	31°C	1.0696	1.0526	0.9996		
	22°C	1.1899	1.0905	1.1243		
	Mean	1.1298	1.0716	1.0620		
Night Temp. Mean	31°C				1.0406	
	22°C				1.1349	

APPENDIX VII

Analyses of variance for the provenance experiment

Source of variation	df.	Sum of squares	Mean squares	F
(i) Diameter increment				
Provenance	4	0.4366	0.1092	19.906**
Day temperature	2	1.5974	0.7987	145.644**
Night temperature	1	1.1450	1.1450	208.801**
Night x provenance	4	0.0930	0.0233	4.241*
Day x provenance	8	0.1775	0.0222	4.045*
Day x night	2	0.0182	0.0091	1.662
Error	8	0.0439	0.0055	
(ii) Relative diameter growth				
Provenance	4	2.3280	0.5820	4.700*
Day temperature	2	8.1500	4.0750	32.911**
Night temperature	1	0.5459	0.5459	4.409*
Night x provenance	4	0.7478	0.1869	1.510
Day x provenance	8	1.9152	0.2394	1.933
Day x night	2	1.2508	0.6254	5.051*
Error	8	0.9906	0.1238	
(iii) Height increment				
Provenance	4	2.2652	0.5663	2.954
Day temperature	2	2.9865	1.4933	7.790*
Night temperature	1	52.0083	52.0083	271.304**
Night x provenance	4	0.9763	0.2441	1.273
Day x provenance	8	3.6233	0.4529	2.363
Day x night	2	3.8765	1.9382	10.111*
Error	8	1.5336	0.1917	
(iv) Relative height growth				
Provenance	4	5.1109	1.2777	5.798*
Day temperature	2	0.8598	0.4299	1.951
Night temperature	1	39.7855	39.7855	180.524**
Night x provenance	4	4.0862	1.0216	4.635*
Day x provenance	8	2.8106	0.3513	1.594
Day x night	2	1.6009	0.8005	3.632
Error	8	1.7631	0.2204	

APPENDIX VII cont'd..

Analyses of variance for the provenance experiment

Source of variation	df.	Sum of squares	Mean squares	F
		(v) Relative growth rate		
Provenance	4	0.001380	0.000345	0.726
Day temperature	2	0.000631	0.000315	0.663
Night temperature	1	0.006258	0.006258	13.160**
Night x provenance	4	0.001283	0.000321	0.675
Day x provenance	8	0.002984	0.000373	0.784
Day x night	2	0.000087	0.000043	0.091
Error	8	0.003804	0.000476	
		(vi) Net assimilation rate		
Provenance	4	0.013592	0.003398	0.362
Day temperature	2	0.200183	0.100092	10.666**
Night temperature	1	0.002075	0.002075	0.221
Night x provenance	4	0.014594	0.003648	0.389
Day x provenance	8	0.107361	0.013420	1.430
Day x night	2	0.010261	0.005131	0.547
Error	8	0.075075	0.009384	
		(vii) Leaf area ratio (1)		
Provenance	4	5030.057	1257.514	9.085**
Day temperature	2	13111.762	6555.881	47.363**
Night temperature	1	23624.275	23624.275	170.675**
Night x provenance	4	1425.658	356.415	2.575
Day x provenance	8	2934.952	366.869	2.650
Day x night	2	202.513	101.256	0.732
Error	8	1107.334	138.417	
		(viii) Leaf area ratio (2)		
Provenance	4	5534.558	1383.640	6.220*
Day temperature	2	15956.439	7978.220	35.863**
Night temperature	1	35398.362	35398.362	159.120**
Night x provenance	4	1957.591	489.400	2.200
Day x provenance	8	1070.321	133.790	0.601
Day x night	2	2324.589	1162.295	5.225
Error	8	1779.706	222.463	

APPENDIX VII cont'd..

Analyses of variance for the provenance experiment

Source of variation	df.	Sum of squares	Mean squares	F
		(ix) $\log_e$ shoot/$\log_e$ root		
Provenance	4	0.06452	0.01613	1.554
Day temperature	2	0.09827	0.04914	4.734
Night temperature	1	0.08335	0.08335	8.030*
Night x provenance	4	0.05462	0.01366	1.316
Day x provenance	8	0.05031	0.00629	0.606
Day x night	2	0.05305	0.02653	2.556
Error	7(1)	0.07267	0.01038	
		(x) $\log_e$ root wt/$\log_e$ total wt		
Provenance	4	0.023945	0.005984	2.431
Day temperature	2	0.107022	0.053511	21.740**
Night temperature	1	0.073974	0.073974	30.053**
Night x provenance	4	0.038805	0.009701	3.941*
Day x provenance	8	0.063274	0.007909	3.213
Day x night	2	0.039146	0.019573	7.952*
Error	8	0.019692	0.002461	
		(xi) $\log_e$ stem wt/$\log_e$ total wt		
Provenance	4	0.152706	0.038177	2.499
Day temperature	2	0.050422	0.025211	1.650
Night temperature	1	0.342807	0.342807	22.442**
Night x provenance	4	0.036466	0.009117	0.597
Day x provenance	8	0.165360	0.020670	1.353
Day x night	2	0.030538	0.015269	1.000
Error	8	0.122203	0.015275	
		(xii) $\log_e$ leaf wt/$\log_e$ total wt		
Provenance	4	0.027653	0.006913	1.182
Day temperature	2	0.026956	0.013478	2.304
Night temperature	1	0.066694	0.066694	11.402**
Night x provenance	4	0.030457	0.007614	1.302
Day x provenance	8	0.063209	0.007901	1.351
Day x night	2	0.011944	0.005972	1.021
Error	8	0.046796	0.005850	

(1) Missing plot estimated.

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